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Photovoltaic Energy Systems

Program Summary

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Preface

The National Photovoltaics Program was initiated to provide focus, direction, and funds for the development of solar photovoltaic power. Its objective is to develop the technology that will permit industry to provide cost-competitive photovoltaic energy systems capable of supplying a significant portion of the nation's energy requirements.

Each year a program summary is prepared which provides an overview of government-sponsored activities within the Fnotovoltaics Program. This summary highlights the ongoing research, development, and demonstration efforts and describes each of the U.S. Department of Energy's (DOE) current photovoltaics projects initiated, renewed, or completed during fiscal year (FY) 1981 (October 1, 1980 through September 30, 1981).

The FY 1981 Photovoltaic Energy Systems Program Summary is a follow-up to the FY 1980 Program Summary, DOE/CE-0012, published in January 1981, and available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

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Section I
Introduction

The conversion of solar power by photovoltaics (PV) has long been recognized as a potentially abundant source of clean, renewable electrical power. Photovoltaic systems require no complex machinery or moving parts; they are basically modular, and therefore adaptable and potentially cost-effective in large as well as small-scale applications.

Photovoltaic solar cells are solid-state devices that instantly and silently convert sunlight directly into electricity. Individual solar cells are interconnected and encapsulated to form a PV module. Groups of modules are then interconnected to form a PV array. The complete PV generating system includes the array plus power-conditioning equipment, wiring, and the necessary auxiliary devices.

The technical feasibility of photovoltaics has been a demonstrated fact for many years, and PV technology for specialized uses is relatively advanced. For example, PV solar cells have been used extensively to provide power for space satellites. However, the relatively high cost of systems being produced has tended to restrict terrestrial applicability to small-scale, remote operations where photovoltaic power systems are commercially successful. To augment the national electrical energy needs significantly, electricity from photovoltaics must be produced at costs competitive with electricity from conventional generating sources.

Section II
The National Photovoltaics Program

This document describes progress in the federally sponsored National Photovoltaics Program during 1981. During the latter half of the year, a number of changes in Federal policy and programmatic emphasis began to be implemented. Current Administration policy for solar energy is based primarily upon the principle of marketplace supply and demand. Thus, activities planned for FY 1982 and beyond are intended to emphasize primarily high payoff research — both basic and generic — to advance the photovoltaic knowledge base. It is intended that this will allow private industry to incorporate the knowledge in systems that are capable of making a significant contribution to the nation's energy supply.

A. History

In the early 1970s, with a forecast of impending worldwide shortages of nonrenewable energy and the nation's increasing dependence upon imported fossil fuels, national emphasis was directed toward the development of reliable alternative energy resources.

In 1975, the National Photovoltaics Program was initiated under the sponsorship of the National Science Foundation. The established program objective was to bring photovoltaic energy systems costs to the point where they would be able to supply a significant portion of the nation's energy requirements — to accelerate the development of reliable and economically viable energy systems while working to stimulate their earliest possible competitive market penetration and widespread use.

On October 24, 1974, the Solar Energy Research, Development, and Demonstration Act (Public Law 93-473) was enacted. The legislative goal was to provide the nation with the option of using solar energy as an alternative source for meeting future terrestrial energy requirements. From 1975 to 1977, the Division of Solar Energy of the Energy Research and Development Administration (ERDA) led the effort in photovoltaics technology development, systems development, and demonstration. In October 1977, ERDA was absorbed by the U.S. Department of Energy (DOE) following passage of the Department of Energy Organization Act (Public Law 95-91).

On November 4, 1978, Congress passed the Solar Photovoltaic Energy Research, Development, and Demonstration Act (Public Law 95-590). This law authorized a 10-year program of accelerated "research, development, and demonstration of solar photovoltaic energy technologies," with the long term objective of producing "electricity from photovoltaic systems cost-competitive with utility-generated electricity from conventional sources," and to resolve the social, technical, environmental, institutional, and legal issues involved in widespread adoption of photovoltaic power systems.

On November 9, 1978, Public Law 95-617, the Public Utility Regulatory Policies Act of 1978 (PURPA) was passed, encouraging purchase of electricity from privately owned electricity generators by utilities at economically neutral rates.

B. Program Organization

The Photovoltaic Energy Technology Division is part of the DOE's Office of Solar Electric Technologies, one of five administrative offices of the Deputy Assistant Secretary for Renewable Energy. This responsibility resides within the DOE Office of the Assistant Secretary for Conservation and Renewable Energy. An overview of this organizational structure is shown in Figure 1-1.

The Photovoltaics Program is managed by the Photovoltaic Energy Technology Division. The Division develops overall Program policy and budgets, and approves plans and strategy. The actual day-to-day administration of the Program elements, however, has been decentralized and is shared by two designated Lead Centers. The

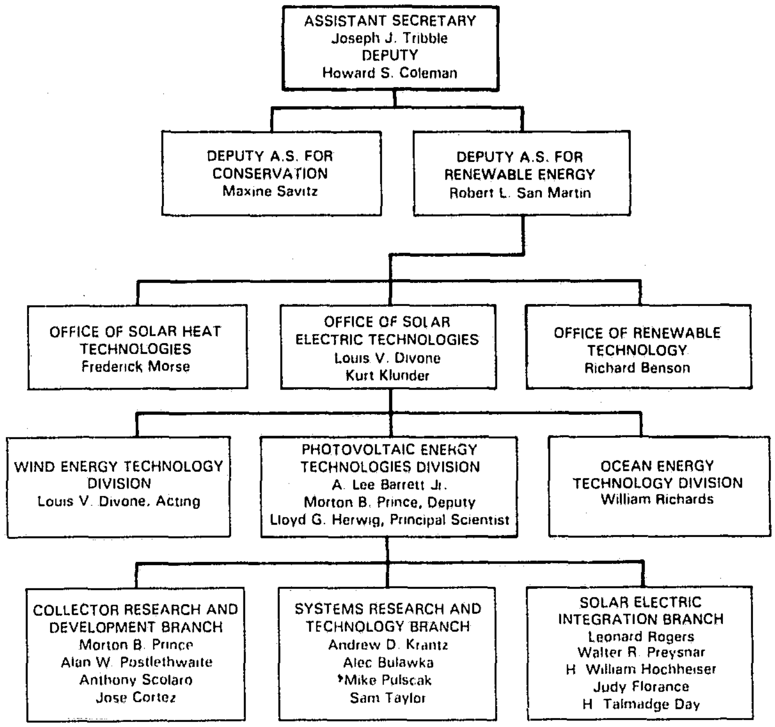

Figure 1-1. Solar Energy Management Organization

Solar Energy Research Institute (SERI), located in Golden, Colorado, is Lead Center for Photovoltaics Advanced Research and Development (AR&D). NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, is Lead Center for Photovoltaics Technology Development and Applications (TD&A). These two Centers manage the detailed planning, assessment, and implementation of the Program to meet the guidelines and objectives established by the DOE Program Office. This includes the coordination of involved Field Center organizations and activities. The TD&A Lead Center is also responsible for management of the Federal Photovoltaic Utilization Program (FPUP) activities. This structure is outlined in Figure 1-2. Both Lead Centers also serve to further promote the development and advancement of photovoltaics within the commercial, industrial, and private sectors.

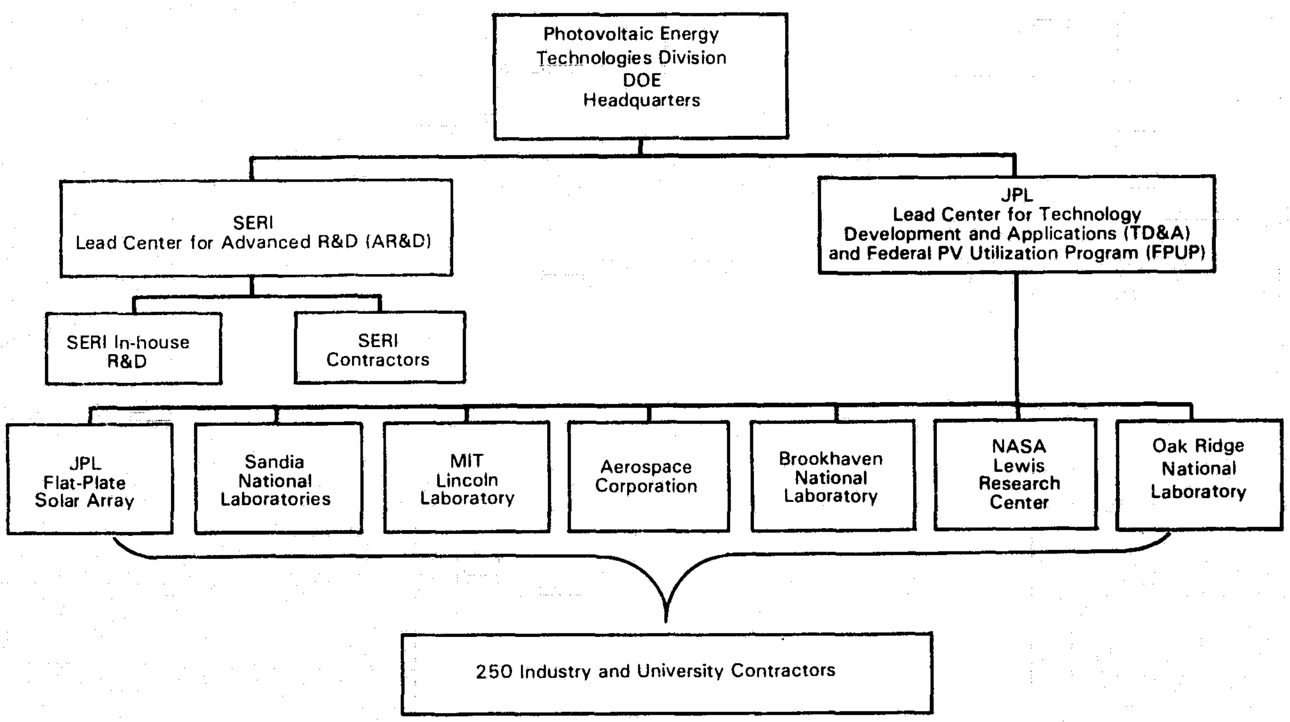

Figure 1-2. Photovoltaics Program Organization

C. Program Plan

Present program strategy is to support critical, high risk, long term research and development on materials, collectors, and systems that have the potential for low cost and high reliability. The goal of this strategy is to increase the potential of photovoltaic power systems as significant, competitive, power-generating options so that private industry can and will produce them for general use.

Specific objectives are:

a. By 1984-85:

Develop photovoltaic materials, devices, and processes having appropriate efficiency, durability, and performance (i.e., technical feasibility) to enable industry to produce $0.70/$W_p$ collectors (1980 dollars).

b. By 1988-90:

Demonstrate technical feasibility of less-than-$0.40/$W_p$ collectors that will lead to $1.10 to $1.80/$W_p$ systems capable of widespread energy supply in the United States.

D. Subprogram Elements

1. Structure

Implementation of the Photovoltaics Program in FY 1981 was carried out within three major technical subprogram elements designed to promote the research, development, and demonstration of proven concepts in a timely and systematic manner:

a. Advanced Research and Development

b. Collector Research and Development

c. Systems Research and Technology.

A fourth element, Planning, Assessment, and Integration (PA&I), provides the named functions as well as mission, economic, and policy analysis for the Photovoltaics Program as a whole. The PA&I element provides the focus for monitoring major milestones and leading assessments of Program progress and funding options analysis through the coordinated effort of each subprogram.

2. Processes

a. *Advanced Research and Development*. Includes investigation of advanced cell concepts, materials, and structures that will result in low cost solar cells, and that will lead to achievement of technical feasibility for various advanced materials. (The term "technical feasibility" is limited to the demonstration of stable and reproducible high efficiency cells.)

b. *Collector Research and Development*. Includes planning, coordination, and integration of the field organization activities in flat-plate and concentrator photovoltaic collector research and development for materials, devices, and processes. Direction is provided for field center activities in addressing high risk, high payoff research activities leading to durable, high efficiency photovoltaic collectors.

c. *Systems Research and Technology*. Includes establishment of PV system performance improvement and cost reduction; identification of alternative approaches in meeting program goals; monitoring of progress against program milestones; definition, planning, development, and implementation of tests and experiments in all application areas; compilation and evaluation of test data and experiment results; provision of information on cost, performance, reliability, user acceptance, and institutional aspects.

Section III
Program Highlights

A. Advanced Research and Development

Implementation of the Advanced Research and Development (AR&D) Subprogram element and associated planning, assessment, and integration activities is the responsibility of the Photovoltaics (PV) Lead Center for AR&D located at the Solar Energy Research Institute (SERI) in Golden, Colorado. The major thrust of this subprogram is to achieve technical feasibility for various advanced material technologies through long term, high risk, and potentially high payoff research and development (R&D). These technologies have the potential for achieving stable and reliable devices with 10% or higher conversion efficiencies and cost potentials of $0.15 to $0.40/W$_p$, which should allow system costs of $1.10 to $1.80/W$_p$. The mission of the PV AR&D Subprogram at SERI is implemented through coordinated subcontracting activities with universities and private industries and through the use of in-house scientific staff for the independent assessment and verification of solar photovoltaic technologies.

Specific activities involve management of subcontracted efforts, research complementary to subcontracted work, development of state-of-the-art measurement and device capabilities, and advanced research. Activities within these programs include:

a. Research in advanced photovoltaic material technologies, including polycrystalline silicon, amorphous materials, cadmium sulfide-based compounds, gallium arsenide, other III-V high efficiency materials, luminescent concentrators, potentially promising materials, electrochemical photovoltaic cells, including cells that use the generated electricity for on-site energy storage and fuel production, and other promising polycrystalline thin-film technologies.

b. Examination of methods to produce self-supported semiconductor thin films at ultrahigh growth rates for photovoltaic device production.

c. Performance of measurements and development of improved measurement techniques to evaluate the characteristics, performance, and durability of photovoltaic devices and materials and help direct research into those areas where improvements and further exploration are most valuable.

d. Development of computational tools for studying the electronic structure of photovoltaic materials leading to macro- and microscopic models for improving solar cell performances.

e. Basic research into the physics and chemistry of the photovoltaic process.

f. Research leading to understanding of the photochemical and photoelectrochemical behavior of photoconversion materials and materials systems.

g. Analysis and research required to understand the integration of advanced photovoltaic technologies into modules and systems.

h. Analyses to help direct the research of photovoltaic materials, devices, and components.

i. Development and provision of accurate and adequate insolation resource data bases, standards, models, conversion algorithms, characterizations, and assessments, as well as development and application of advanced instrumentation for insolation measurements.

j. Research on advanced components necessary for efficient use of advanced photovoltaic technologies.

k. Evaluation of strategic materials availability and related socio-enviro-economic questions.

The AR&D Subprogram is made up of the elements described below.

1. Amorphous Thin Films

This task has, as its objectives, research in amorphous silicon (a-Si) and other amorphous thin-film materials to identify barriers currently limiting photovoltaic conversion efficiencies to 6% to 8% and to develop techniques required to extend the efficiency to 10% or greater. The higher efficiency cells should promise durability and low cost of fabrication in accordance with existing DOE guidelines. Ongoing subcontract work will be selectively renewed in FY 1982 with emphasis toward the most promising preparation techniques (glow discharge, reactive sputtering, and chemical vapor deposition), studies of basic mechanisms, and emerging materials and technologies. An expanded program started in FY 1981 and covering processing research using the glow discharge deposition technique will be continued. In-house research and evaluation functions initiated at SERI will be continued and expanded. These functions include an RF glow discharge deposition system and measurements of hole diffusion length by the surface-photovoltage technique.

2. High Efficiency Photovoltaic Materials

This task includes subcontracted research and in-house support activities on high efficiency and/or very low cost polycrystalline silicon solar cells, thin-film gallium arsenide, high efficiency concentrator solar cells, and luminescent solar collectors. The FY 1982 objective for the polycrystalline silicon area is to further investigate and develop two novel silicon-sheet technologies (Edge-Supported Pulling and Low Angle Silicon Sheet) toward their low cost potentials. For the gallium arsenide area, the objectives are: to achieve 9% efficient, large area, thin-film (less than 10 mil thickness) polycrystalline p/n junction cells; and to achieve 12% efficient, 1-cm area GaAs solar cells on germanium-coated silicon substrates. The FY 1982 objectives for the high efficiency concentrator solar cells are to develop metal-interconnected cascade solar cells with a goal of 25% efficiency; to investigate the mechanisms that control the performance of InP concentrator cells; and to improve metal-organic CVD for the growth of III-V cascade solar cells, especially with respect to the growth for the tunnel junction interconnections. In the luminescent solar collectors (LSC) area, the objectives are to synthesize and characterize stable organic dyes that exhibit appropriately large Stokes shifts, quantum yields, and solar absorption for use in efficient LSC s and to study transition metal inorganic host materials suited for development into efficient LSC systems.

3. Polycrystalline Thin Films

This task consists of subcontracted research using materials and deposition techniques that are material-and-energy conservative. These areas include cadmium sulfide/copper binary or ternary compound heterojunctions, electrochemical photovoltaic cells, and other polycrystalline thin-film technologies. In-house support research is carried out to assess and complement the subcontracted activities. The FY 1982 objectives for the cadmium sulfide area are to carry out research on thin films of Cu_2S and $CuInSe_2$-based devices to obtain efficiencies of greater than 11%, and to determine and control the long term stability of such cells. The objectives of the photoelectrochemical cell (PEC) area are to achieve high conversion efficiencies and to demonstrate stability in polycrystalline or amorphous semiconductor/electrolyte systems having associated storage potential. Other objectives are to investigate hot-wall vacuum evaporation and chemical vapor deposition of thin-film CdTe solar cells, to understand the doping mechanisms for Zn_3P_2, and to develop appropriate solar cell device structures.

4. Solid-State Research

Efforts are focused toward high solar cell efficiencies (single-crystal materials and multijunction devices), materials purification, and innovative thin-film research that leads to state-of-the-art photovoltaic material and device processing techniques. The overall objective is to continue to build a "laboratory of excellence" in solid-state photovoltaic research.

5. Photovoltaic Devices and Measurements

The objectives here are to advance and improve the range and reliability of material and device measurements for photovoltaics, increase the understanding of critical materials and device parameters that limit performance characteristics and operational lifetime, and establish PV measurement and processing laboratory facilities to provide support for researchers (internal programs and subcontractors) in the critical evaluation and advancement of their photovoltaic technologies. Critical areas of emphasis include implementation of proper spectral response and current-voltage measurement procedures for devices; microcharacterization of thin-film devices; completion of new or modified measurement techniques for thin-film, polycrystalline photovoltaic materials/devices; evaluation of advanced techniques for processing high efficiency concentrator cells; and the quantification of impurities, especially hydrogen, in amorphous solar cells.

6. Photovoltaic Performance Criteria and Test Method Development

SERI is participating in the development of performance criteria and test methods under the direction of the JPL Lead Center for Technology Development and Application. Criteria and test method development in FY 1982 will come from task group work and from specific procurements placed in FY 1981, but continuing into FY 1982. JPL will lead one task group (PV arrays) and SERI will lead the other two (Power Conditioning, etc., and Systems). These developments will be published in revisions to the Interim Performance Criteria for PV Systems.

Significant FY 1981 accomplishments for AR&D include:

a. Polycrystalline silicon exploratory development program resulted in Motorola moving directly to a joint venture with Shell Oil that expects to produce a commercial product by the mid-1980s.

b. Developed a prototype series-connected, high voltage GaAs concentrator cell, with a 19.6% efficiency.

c. Developed a prototype AlGaAs/GaAs cascade structure, grown by LPE with tunnel junction interconnects having a 16.9% efficiency.

d. Demonstrated 12.4% efficiency for a single-crystal electrochemical CdSe cell in an aqueous ferrol electrolyte.

e. Demonstrated high efficiencies for single-crystal PEC cells: 14%-GaAs, 16%-CdTe, 10.4%-WSe_2 and 9.4%-$MoSe_2$.

f. Demonstrated 17% efficient, GaAs, thin-separated-film solar cells.

g. Demonstrated decreased deposition time (5 min. compared with 30 to 60 min.) for high efficiency a-Si:H PIN cells made by dc glow discharge method.

h. Demonstrated 9.93% efficient (Cd,Zn) S/$CuInSe_2$ cell, 5-μm thick.

i. Fabricated large-area polycrystalline solar cells on laser beam RTR material; 11.2% efficiency on 32-cm^2 area attained.

j. Developed a reproducible 6.1% a-Si:H PIN cell area of 1.2 cm^2, using glow discharge preparation.

k. Demonstrated 11.7% efficient, n^+p, thin-film GaAs solar cell on a Ge/Si substrate.

l. Demonstrated polycrystalline GaAs solar cells of 8.9% efficiency for MOS structures of 9 cm^2 area and 7.1% efficiency for homojunction devices of 8 cm^2.

m. Demonstrated silicon ribbon growth by the low angle silicon sheet growth technique during one hour operation at 55 cm/min. of a ribbon 33-m long, 5-cm wide and 0.5-mm thick. Cells of 10.5% efficiency were fabricated from this material.

n. Fabricated improved PN junction and MIS/SIS polycrystalline silicon cells; increased efficiency from 5% to 8% in 1976 to 10% to 13% in 1981.

o. Demonstrated efficiency of 8.3% for CdS/$CuInSe_2$ cell with an area of 8 cm^2 and 9.4% with an area of 1 cm^2.

p. Developed (Cd,Zn) S/Cu_2S thin-film cell having efficiency of 10.2% with an area of 1 cm^2.

During 1981, studies were continued in the following areas: long term stability of CdS/Cu_2S and CdS/Cu ternary heterojunction PV devices, grain boundary problems in polycrystalline silicon, materials availability, and physical phenomena in advanced amorphous materials. Also continued were theoretical analysis and characterization of passivation treatments, evaluation of promising new materials, investigation of multijunction cells, and assessment of technology options for high efficiency concentrators.

Planned activities for FY 1982 will continue the emphasis on development on high efficiency cells, cell processing techniques, interface analysis, and measurement techniques. They include:

a. Increase in the efficiency of II-VI and mixed II-VI polycrystalline thin-film cells.

b. Investigation and development of a scientific database for the edge-supported pulling and low-angle silicon sheet technologies with high growth rates with acceptable efficiencies.

c. Research on thin-film $CdS/CuInSe_2$ heterojunction devices formed by vacuum evaporation and/or sputtering.

d. Comparative evaluation of tunnel junctions, superlattice structures, and metal-interconnect schemes for electrical coupling of junctions for high efficiency cascade cells.

e. Achievement of a-Si:H PIN cell efficiency of 7% for 1-cm^2 area.

f. Demonstration of efficient, large-area cells through low temperature GaAs growth.

g. Continued development of efficient CdTe homo- or heterojunction cell.

h. Assessment of AlGaAs/GaAs versus AlGaAsSb/GaAsSb cascade cell technologies.

B. Collector Research and Development

Implementation of the Collector Research and Development Subprogram, the Systems Research and Technology Subprogram, and the associated Planning, Analysis, and Integration activities is the responsibility of the Photovoltaics Lead Center for Technology Development and Applications at the Jet Propulsion Laboratory (JPL) in Pasadena, California.

Collector Research and Development involves the long range, high risk, high payoff innovative development of materials, processes, and manufacturing techniques for flat-plate and concentrator collectors that have the potential for achievement of less than $0.70/$W_p$ (1980 dollars) and long life expectancy (20 years or greater). Technology feasibility of $2.80/$W_p$ has been achieved. Excellent progress toward $0.70/$W_p$ collectors was made during 1981; several collector approaches may be able to exceed that cost target goal. Refer to Table 1-1 for cost targets.

Table 1-1. Technology Feasibility Cost Targets

Application and Year	Collector Cost (FOB) ($/$W_p$)	System Cost* ($/$W_p$)	Production Scale (MW_p/year)
Remote Stand-Alone 1982	≤2.80**	6.13	--
Residential 1986	≤ 0.70	1.60-2.20	100-1000
Intermediate Load Center 1986	≤0.70	1.60-2.60	100-1000
Central Station 1990	0.15-0.40	1.10-1.80	500-2500

* System cost correlates with production scale
** All figures are quoted in 1980 dollars

Flat-plate solar collector research and development is the responsibility of the JPL Flat-Plate Solar Array Project (FSA). The present effort is based on the use of single and polycrystalline silicon cells which utilize sawed ingots or shaped ribbon sheets. Concentrator collector development is being done by Sandia Laboratories, Albuquerque.

Table 1-2 displays some of the Program-sponsored developments that have been adopted by flat-plate module manufacturers as examples of the continuing industrial technology transfer.

Table 1-2. Program-Sponsored Developments Adopted By Flat-Plate Module Manufacturers

Materials	Cell Processing	Module Fabrication	Cost Analysis
Melt replenishment for Czochralski crystal growth	Spray-on-anti-reflection coatings	Automated cell string assembly	SAMICS manufacturing cost analysis methodology
Multiple crystal pulls from single crucible	Laser scribing	Glass superstrate PVB and EVA module encapsulant systems	
	Thick-film technique for back-surface field junctions		
Silicon ribbon growth automation		Module standards	
EVA encapsulant for flat-plate modules	Ion-implanted junction	Laminated structures	
	Texture etched front surface	Interconnect redundance	
		Environmental testing standards	
		Safety standards	
		Reliability data and design features	

1. Flat-Plate Collectors

The Flat-Plate Solar Array Project is sponsoring research on a variety of solar cell types made from both single-crystal and semicrystalline silicon ingots, as well as silicon ribbons. The focus of this research is toward long term, high risk, potentially high payoff activity that the photovoltaics industry will not undertake because of the risk associated with the work.

The FSA Project has five principal research areas; activity in each area aims at solving critical elements of the conversion of silicon material into a solar photovoltaic collector. The five areas are: (1) refinement of silica into inexpensive polysilicon feedstock; (2) formation of large-area crystalline sheets to be used for solar cells; (3) research into the problems of solar cell environmental isolation materials; (4) investigation of process sequences necessary for the formation of cells and modules; and (5) engineering sciences investigations into failure mechanisms, safety, and fault-tolerant module designs.

Accomplishments during FY 1981 reflect a mixture of work under the previous direction of technology development assistance to the PV industry and under the new research direction as defined above:

a. Experimental research on silicon material refinement resulted in progress in several key areas of investigation: (1) the characterization and definition of silicon material requirements for high efficiency solar cells, (2) new concepts for fluidized-bed reactor technology for chlorosilane/silane chemical systems, (3) new reactor concepts that enable significant increases in silicon deposition rates using chlorosilane and silane precursors, and (d) continuing ongoing efforts in the silane to silicon process.

b. Research on the critical elements of silicon sheet growth to achieve a silicon sheet technology compatible with future solar cell requirements experienced progress in several areas: (1) work was virtually completed on the advanced Czochralski continuous melt replenishment growth unit, (2) research was initiated on the limits to crystallization rates in silicon growth, (3) experimental activity was started on the investigation of residual thermal stresses generated during high speed growth of wide and thin silicon ribbons, and (4) important insights were gained in the basic mechanisms of cutting silicon and the effects of silicon surface properties on measurable performance parameters.

c. Module environmental isolation research yielded important information in the understanding of aging degradation characteristics and their influence upon module durability and reliability. Specifically, advances in the following areas of investigation were achieved: long term photothermal degradation mechanisms in polymers; modeling and validation; encapsulant-interface stability as affected by bonding techniques; dissimilar materials in operational environments; and accelerated life and durability testing techniques as applicable to life prediction.

d. In the cell and module formation research area, the module experimental system development unit concepts have been reorganized to focus upon only critical elements requiring in-depth research. Achievements in the areas of surface preparation were realized, specifically in hot-sprayed antireflective coatings; likewise, in the junction formation activity a pulsed electron-beam annealer was successfully demonstrated; in metallization, copper paste was successfully used for a back surface field; ion milling of excess metal was demonstrated; and the Midfilm Process was successfully developed for silver and a molybdenum compound. In module formation research, programmable robotics work was completed and the ultrasonic bonding technique using a rolling spot was demonstrated.

e. The engineering sciences research developed an array structure that is estimated to cost less than half of the program's allocated cost of $50/m^2$. The structure uses a planar frame made of members formed from light-gauge galvanized steel sheet and is supported in the field by treated-wood trusses using the trenched and backfilled soil to carry uplift wind loads and thus to eliminate reinforced concrete foundations. The structure is estimated to cost less than $25/m^2$, including all markup, shipping, and installation.

2. Concentrator Collectors

The Concentrator Collector Project is developing silicon solar cell concentrator arrays that can meet the collector cost targets. Research is currently based primarily upon Fresnel lens design with silicon, gallium arsenide, and other advanced material cells. Major accomplishments in FY 1981 include:

a. Record conversion efficiencies were established by photovoltaic concentrator modules of three types:

   70X point-focus Fresnel module using planar junction Si cells — 14%

   470X point-focus Fresnel module using AlGaAs cells — 16%

   450X beam-splitter module using dichroic filters, Si cells, and AlGaAs cells — 20%

   Each of these represents a higher solar-to-electric conversion efficiency than that achieved by any other photovoltaic technology.

b. 160 pedestal-mounted point-focus Fresnel concentrator arrays were installed near Riyadh, Saudi Arabia, in the world's largest photovoltaic project, the 300-kW_P SOLERAS project.

c. Fresnel lens concentrators, point and line focus, were identified as being the best design concepts for photovoltaic concentrators, based on results of experimental and analytical research. Research on reflective concentrator concepts, including parabolic troughs and dishes for photovoltaics, has been dropped.

d. Research on higher concentration modules (600-1000X) using domed Fresnel lenses and etched multiple vertical junction (EMVJ) Si cells established that these advanced concepts are feasible.

e. DOE placed a fixed price contract for a completely installed photovoltaic concentrator array field of 225 kW at $11/W.

f. Prototypes of several different baseline module designs were tested in the 11%-14% conversion efficiency range.

g. Research directed toward a more fundamental understanding of the performance, reliability, and durability of module components, including module materials, optics, concentrator cell mounts, and cell encapsulants was greatly intensified in FY 1981.

3. Planned Activities for FY 1982

Activities in FY 1982 will continue to emphasize long range, high payoff, high risk research and development on collectors (both flat-plate and concentrator). This effort will be aimed at achieving technical feasibility for industry to produce collectors, at \$0.70/W_p by 1984-85 and \$0.40/W_p by 1988-90, with 20-years-or-greater collector lifetime. This research and development will concentrate on materials, processes, device concepts, and measurement techniques:

a. Continuation of research and development on critical elements of silicon purification processes.

b. Completion of research and development on silicon sheet growth, wide and thin ribbon growth, and basic mechanisms studies related to cutting of ingots.

c. Continuation of research and development on materials and processes for protection of collectors from the terrestrial environment.

d. Continuation of research and development on high concentration, high performance collector modules.

e. Continuation of research and development on high efficiency structures, optimization, and novel cell structures (multilayer, multijunction, optical trapping).

f. Continuation of accelerated life test methodology, life degradation factors (corrosion, electrochemical reaction for example) and standardization of test methods.

g. Completion of module experimental system development (MEPSDU) activities.

h. Continuation of research and development on materials leading to collector performance optimizatioı (surface passivation; contact stability; grain boundary interaction; novel, thin-film conductive coatings)

i. Initiation of research on materials interface problems in advanced concepts as related to electrical interconnection and environmental packaging.

C. Systems Research and Technology

The objective of the Systems Research and Technology Subprogram is to establish the potential for PV system performance improvement and reliability necessary to meet the requirements for a life-cycle cost competitive, renewable source of electricity. The potential of industry (state of the art) must be periodically assessed to ensure that limited resources are focused on the critical development problems, and that a careful selection of program alternatives can be made to fit available resources.

The objective of the Systems Tests portion of the subprogram is to respond to requirements for experimental information by defining, planning, developing, and implementing tests and application experiments in all application sectors. These incorporate systems designs and information requirements developed by the subprogram, and institutional guidelines and information requirements defined by the Planning Assessment and Integration (PA&I) element, as well as information requirements of potential users of photovoltaic power systems. Test data are compiled and evaluated, and information furnished on cost, performance, reliability, user acceptance, and institutional aspects. Activity is focused into an experimentation area and a data analysis and information dissemination area.

The scope of the Systems Research and Technology Subprogram function includes the management within the DOE Photovoltaic Program of the following activities at the implementing Field Centers:

a. Systems Research

(1) Technology Assessment

(2) Requirements Definition

(3) System Evaluation and Prototype Testing

(4) System Design and Analysis

(5) Development of Design Tools

(6) Support Development of Building Codes and Standards

(7) Performance Criteria and Test Standards

(8) Environmental, Health, and Safety Impacts Assessment

b. Subsystems Research and Development

(1) Array Subsystem Research in Flat-Plate Arrays and Concentrator Arrays

(2) Power Processor Subsystem Research

(3) Subsystem Evaluation and Prototype Testing

c. Systems Tests

(1) Natural Bridges National Monument

(2) PRDA Projects 35 and 38

(3) WBNO — Bryan, Ohio

(4) Mt. Laguna Air Force Station

(5) Northeast RES

(6) Southwest RES

(7) Mississippi County Community College

To date, potential market sectors have been identified and their technical, economic, and institutional features examined. Early conceptual design and analysis efforts have provided a basis for detailed system and subsystem tradeoffs. Currently, reference designs for small systems are complete, with designs for medium- and large-sized systems in progress. The final step of summarizing and abstracting program design experience into design handbooks for transfer to the private sector has been initiated. The major field center systems definition and development work is being carried out by the Sandia National Laboratories. In addition, experimental applications of various PV systems are providing the opportunity to assess and resolve technological issues identified during design, fabrication, installation, operation, and maintenance of systems operating under field conditions. Sandia National Laboratories, Albuquerque; NASA/Lewis Research Center; Massachusetts Institute of Technology/Lincoln Laboratory and Aerospace Corporation Field Centers have all played significant roles in this area.

1. Systems Research

Systems Research begins by establishing initial performance requirements for systems and subsystems. These requirements constitute criteria which ensure that the systems will be technologically and economically competitive producers of energy. Model systems are designed and analyzed on the basis of the initial performance requirements. Such systems provide an opportunity to evaluate and refine initial system and subsystem cost goals in support of goal achievement. Evaluation of systems designed according to established performance requirements serves to validate or justify refinements in those requirements, while yielding test data to support improved system reliability. Development of simplified sizing and design procedures is intended to accelerate wide acceptance of photovoltaics through facilitating their adoption by architects, developers, and contractors. Similarly, the support of codes and standards development is intended to foster market penetration through the development of appropriate codes prior to the broad-scale commercial appearance of PV systems. The early consideration of environmental, health, and safety requirements permits the development of systems which are occupationally and socially attractive. Finally, adequate consideration of performance and reliability is essential to meeting life-cycle cost goals.

Major accomplishments in FY 1981 included:

a. Development of "Photovoltaic Stand-Alone Systems, Preliminary Engineering Design Handbook."

b. Completion of residential reference designs and initiation of independent cost element analysis to determine subsystem cost drivers.

c. Publication of a design handbook for photovoltaic grid-connected systems. This document provides a simplified design performance analysis for use by architects and engineers.

d. Analysis of the effect of future energy contingencies on photovoltaic system value as a function of region and design.

e. Examination of health risks associated with fabrication and decentralized use of various types of PV cells:

   (1) Developed a system of reference material to support risk analysis.

   (2) Compiled data on the toxicology of silicon and cadmium compounds and hydrogen fluoride.

   (3) Prepared a report on the occupational risks of the PV energy cycle.

2. Subsystems Research and Development

Subsystems Research and Development addresses array, power processor, and energy storage subsystems appropriate to the achievement of all cost, performance, and reliability goals for PV systems. Representative subsystem activities include the examination of design and cost tradeoffs, evaluation of installation and maintenance strategies, and establishment of safety criteria.

Major accomplishments in FY 1981 included:

a. Completion of four parallel design efforts for advanced power conditioning subsystems for small- and intermediate-sized photovoltaic applications.

b. Development of a baseline specification for power conditioners in small grid-connected applications.

c. Delivery and initial engineering evaluation of prototype self-commutated power conditioners for small (less than 10 kW) applications.

d. Completion of optimized flat panel array field designs for medium-sized systems to demonstrate reduced balance-of-system costs through integrated subsystems and standardized designs.

e. Development of integrated structural subsystem designs for large-sized flat panel systems.

f. Test and evaluation of Redox energy storage systems with a photovoltaic power source.

3. Systems Test

The objective of the Systems Test function is to respond to requirements for experimental information by defining, planning, developing, and implementing tests and applications experiments for all types of applications. In addition to the systems design information requirements satisfied, these experiments incorporate institutional guidelines as well as information furnished on cost, performance, reliability, user acceptance, and institutional aspects. Systems Test is also responsible for fostering the development of a supply infrastructure for system-ready technology, and for promoting widespread awareness of photovoltaic systems. Activity is focused in two major areas:

a. Experimentation

b. Data Analysis and Information.

Major accomplishments during FY 1981 are as follows:

a. The largest application in the world, the 300-kW_p SOLERAS Project in Saudi Arabia, became operational in December.

b. Initial operation began of four intermediate-sized photovoltaic system application experiments.

c. A data acquisition and reduction system supporting the photovoltaic system application experiments became operational and is used to generate performance summaries on a monthly basis.

d. The Mississippi County Community College 240-kW_p concentrator system was installed.

e. The Northwest Mississippi Junior College 100-kW_p system is 40% complete.

f. Proposals for the Georgetown University 300-kW_p flat-plate system are due in January 1982, with a contract selection scheduled for June 1982.

g. The first grid-connected Initial System Evaluation Experiment lived-in residence was constructed in Carlisle, Massachusetts, and includes a PV power system. The PV power system was first tested in February 1981, and the house was completed and ready for occupancy in May 1981.

h. Five prototype residential photovoltaic systems were constructed at the Northeast Residential Experiment Station in Concord, Massachusetts — four supplied by industry participants in the Residential Project and one in-house design. The five systems were completed between November 1980 and September 1981. Eight prototype residential systems were constructed at the Southwest Residential Experiment Station in Las Cruces, New Mexico. Completion of these systems was between April and September 1981. Comprehensive evaluation of system performance and reliability during both normal and extreme operating conditions has begun at both experiment stations. In addition, information on operation and maintenance expenses is being accumulated. Cost reports itemizing the materials and labor involved in system construction were provided by the system contractors. The information available from the testing of these first-of-their-kind systems will provide direction of efforts to develop safe, reliable, residential photovoltaic systems by the mid-to-late 1980s.

i. An active program of information exchange with the elements of U.S. industry likely to be involved in photovoltaic projects was continued, with the objectives of keeping the Photovoltaics Program in touch with the needs of the user community and of fostering the transfer of cost-effective photovoltaic technology to the private sector. Information provided to utilities and suppliers is believed to have contributed to the formation of plans for projects that now exist wholly within the private sector.

j. Analyses were made of the value of photovoltaic generation in the current (1980) electricity generation configuration of the Southern California Edison (SCE) system and in the configurations of 1985 and 1995, as defined in 1979 SCE projections. These analyses, which included detailed comparisons of fuel costs and generation reliability in systems with and without photovoltaic plants, indicated that photovoltaic generation would be worth \$1600/kW_p in the 1980 configuration, \$1700/kW_p in the 1985 mix, and \$1900/kW_p in 1995, with 90% to 95% of this value attributable to fuel (oil) savings. A similar analysis was made of the value of photovoltaics plants in the 1981 configuration of the Los Angeles Department of Water and Power (LADWP). Evaluation of photovoltaic generation in the projected 1994 LADWP configuration is now under way. These results indicate that when specific utilities with favorable characteristics are examined, significant opportunities can be identified for photovoltaic plants that cost \$1.50 to \$2.00/W_p (i.e., that use \$0.70/W_p baseline technology collector modules).

k. A worldwide study was conducted on the market for photovoltaics in three areas: rural village power; cottage industry power; and agricultural applications. Country-specific agriculture reports were prepared for the Philippines, Mexico, Niger, Morocco, and Colombia.

l. A PV-powered refrigerator system was developed to meet the specifications of the World Health Organization and the Center for Disease Control for the purpose of vaccine preservation in remote areas. Fourteen small PV-powered experiments were transferred to six cooperating user agencies. Multi-language PV displays and brochures were made available at international energy trade shows and conferences in Mexico, Jamaica, and Kenya.

Planned activities for FY 1982 include:

a. Substantially revise existing plans to reflect alterations in the overall PV Program structure and emphasis. The revised plans will identify specific paths to advance photovoltaic systems from their present status to that of the Program goals.

b. Continue the review of existing experiments to assess their effectiveness in meeting the Photovoltaics Program goals. Assessments will be made in the areas of performance, cost, reliability, safety, and environmental/institutional interfaces.

c. Continue data analysis and information dissemination reviews with the Field Centers to ensure that appropriate information is being developed by the experiments.

d. Complete a power-conditioning technical status summary, including descriptions of available and proposed hardware.

e. Prepare a detailed program plan for implementing system level technology transfer, with the participation of the implementing Field Centers.

D. Planning, Assessment, and Integration

The objectives of the Planning, Assessment, and Integration element of the program are to provide the named functions as well as mission, economic, and policy analysis for the program as a whole. The PA&I element has been involved most recently in efforts to redirect the program toward higher risk research activities. Activities included developing the multiyear program plan and redefinition of strategic milestones, resetting of program priorities, and preparation of Sunset Review documents needed to satisfy DOE and congressional requirements. Major accomplishments of this program element during 1981 are as follows:

a. Several reports that culminated activities to review the program cost/price goals were published, including reports on residential break-even prices.

b. Documentation, for several models that provide potential users with economic analysis tools, was published. The models are: SYSGEN, documented in "Electric Power Generation System Probabilisitic Production Costing and Reliability Analysis;" LCP, documented in "Lifetime Cost and Performance Model for Distributed Photovoltaic Systems;" APSEAM, documented in two drafts, "A Non-Mathematical Description of the Alternative Power System Economic Analysis Model (APSEAM)," and "The Calculational Detail of APSEAM;" and OMEGA, documented in "A Normative Price for Energy from an Electricity Generation System: An Owner-Dependent Methodology for Energy Generation (System) Assessment (OMEGA)."

c. A three volume report with an executive summary: "Photovoltaics as a Terrestrial Energy Source" was published. The report discusses the use of photovoltaic systems for terrestrial applications.

Section IV
Federal Photovoltaic Utilization Program

The FPUP effort was established in 1978 to procure photovoltaic systems for use on Federal facilities. The objectives established in the enabling legislation provide for the acquisition of solar electric systems at an annual level substantial enough to permit the use of advanced production techniques by the suppliers of such systems. Further, the goals of the program as established by Congress, are to:

1. Accelerate the growth of a commercially viable and competitive industry to make photovoltaic solar electric systems available to the general public as an option to reduce national consumption of fossil fuel.
2. Reduce fossil fuel costs to the Federal Government.
3. Stimulate the general use within the Federal Government of methods for the minimization of life-cycle cost.
4. Develop performance data on the program.

The program is divided into cycles. The various cycles have different emphases, ranging from small remote systems in Cycle I to larger, grid-connected applications in Cycle IV.

Cycle I was initiated in the fall of 1978. It resulted in the receipt of Federal agency proposals for 1603 photovoltaic projects. Of these, 1538 were determined to be cost-effective at current installed system prices and were approved for funding at a total cost of about $10 million. Total peak kilowatt output for Cycle I is 216. Cycles II and III were initiated in FY 1979. Cycle II proposals from Federal agencies were received in June 1979, and a total of $5 million in additional projects was approved. Total peak kilowatt output for Cycle II is 182.

During FY 1980, in response to the FPUP Cycle III request, 432 proposals were received from Federal agencies for intermediate and remote stand-alone applications. Twenty-nine of these applications were selected, representing 13 Federal agencies. The selected applications had a total estimated cost in excess of $4.9 million and a total estimated power of 118 kW_p. For FPUP Cycle IV residential and selected intermediate grid-connected applications, 62 proposals with an estimated value of $62 million were received from Federal agencies. From the Cycle IV proposals, seven applications with an estimated value of $2.9 million and a total estimated power of 85 kW_p were selected by an evaluation committee in June 1980. Through FY 1981 a total of 81 photovoltaic applications representing approximately 600 kW_p had been funded under FPUP.

FPUP applications have involved many different Federal agencies interested in a wide variety of photovoltaic applications installed in diverse geographic locations and environments. Because of these features, critical photovoltaic system experience has been provided to key personnel in Federal agencies and valuable practical information has been fed back to the photovoltaics industry and R&D effort.

Federal Photovoltaic Utilization Program photovoltaic applications are being implemented by five agencies of the U.S. Department of Energy: Bonneville Power Administration, Idaho Operations Office, Nevada Operations Office, Oak Ridge National Laboratory, and Western Area Power Administration. A summary of the individual DOE applications being implemented by the participating agencies is listed in Table 1-3.

The FPUP continues to provide support to Federal agencies as systems are procured and installed. The applications are monitored on a regular basis, and a set of performance data is being developed to support improved reliability in future applications. The status of major applications that have yet to be implemented is shown in Table 1-4.

Table 1-3. Summary of DOE Application Being Implemented by Participating Agencies

Agency	Type	Title	Peak Kilowatts
Bonneville Power Administration	Beacon Flash	Transmission Tower Aircraft Warning Lights, Various (5)	7.500
	Repeater Special Purpose	Radio Repeater The Dalles, OR (1)	0.030
	Water Pump	Portable Water Pump Madras, OR (1)	0.888
	Beacon Flash	Transmission Tower Aircraft Warning Lights, Various (6)	1.800
	Submarine Cable	Cathodic Prototype Lopez Island, WA (2)	0.020
	Transmission	Cathodic Prototype, OR (10)	0.250
	Tower Office Building	Office/Maintenance Building, Redmond, OR (1)	10.000
Idaho Operations Office	Meteorological Sensor	Environmental Data Collector, Lemhi Pass/Salmon, ID (1)	0.080
Nevada Operations Office	Meteorological Sensor	Ground Motion Station Yucca Mountain, NV (8)	0.200
	Meteorological Sensor	Environmental Station Nevada Test Site, NV (1)	1.000
	Repeater Special Purpose	Radio Repeater Cave Mountain Nevada Test Site, NV (1)	1.300
	Radiation Sampler	Tone Barrel Nevada Test Site, NV (6)	0.450
	Radiation Sampler	Tritium Sampler Nevada Test Site, NV (6)	0.150
	Water Pump	Water Quality Monitor Nevada Test Site, NV (1)	12.900
Oak Ridge National Laboratory	Climatic Change Monitor	Portable Precision Gauge Oak Ridge, TN (1)	0.090
Western Area Power Administration	Repeater Special Purpose	UHF/VHF Radio Repeater Cunningham Mountain, AZ (1)	2.000

Table 1-4. Major Applications To Be Implemented

Agency	Location	Description	kWp
DHHS/IHS	Various Sites, AZ	Individual Indian Homes	TBU
DOC/NOAA	American Samoa	Meteorological Station	10.5
DOD/USA	Fort Huachuca, AZ	Holman Guest House	6
DOD/USA	White Sands Proving Ground, NM	Instrumentation Van with Trailer	4
DOD/USA	Aberdeen Proving Ground, MD	Projectile Velocimeter	2.6
DOD/USA	Dugway Proving Ground, UT	Meteorological Data System	6.6
DOD/USAF	Kirtland AFB, Albuquerque, NM	Military Housing Unit	2
DOD/USAF	Tyndall AFB, Panama City, FL	Military Housing Unit	2
DOD/USAF	McClellan AFB, Sacramento, CA	General Store/Mini-Market	25
DOD/USA	Bermuda, U.K.	Tudor Hill Research Laboratory	25
DOD/USA	Twenty Nine Palms, CA	Observation Post	10
DOD/USA	San Clemente Island, CA	Telephone Exchange	8.5
DOE/BPA	Redmond, OR	Maintenance/Office Building	10
DOI/BIA	Various Sites: AZ, NM, UT	Individual Homes, Zuni Indians	18
DOI/NPS	Anacapa Island, CA	Anacapa Island Historical Site	2
DOS	Dakar, Senegal, Africa	American Embassy	17
DOT/USCG	Various Sites	Navigational Aids	50
GSA	San Antonio, TX	Southwest Intergovernmental Training Center	25
TRS/USCS	Trailcreek, MT	Border Inspection Station	2
TVA	Chattanooga, TN	Individual Homes and Commercial Center	25

Section V
Summary

In keeping with the goals and intent of RD&D legislation, the objective of the U.S. Department of Energy's Photovoltaics Program is to develop photovoltaic energy systems capable of supplying a significant portion of the nation's energy requirements. The program goal is to conduct research that will foster the early development of economically competitive, commercially available systems capable of supplying safe and reliable electrical power to a wide variety of users. This will be accomplished through substantial research and development efforts aimed at achieving major cost reductions in components and systems.

Distributed, grid-connected commercial and residential systems should be able to displace significant amounts of conventionally generated electricity, first in the Southwest and Southeast and subsequently throughout much of the United States. Intermediate-sized commercial, institutional, and industrial on-site systems should provide a similar option. Finally, utilities should ultimately be able to augment their generating capacity with larger scale systems. As part of the DOE sequence of Advanced Research and Development, Collector Research and Development, Systems Research, and Systems Test, real-world testing is being pursued with residential, industrial, institutional, and commercial systems to establish their feasibility and readiness to meet market, economic, and other requirements.

Appendix 1
Directing Organizations

Jet Propulsion Laboratory (JPL)
4800 Oak Grove Drive (M.S. 502-422)
Pasadena, CA 91109

Massachusetts Institute of Technology
P.O. Box 73
Lexington, MA 02173

NASA/Lewis Research Center
2100 Brookpark Road
Cleveland, OH 33135

Sandia National Laboratories
Albuquerque, NM 87185

Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115

Appendix 2
Index of Current Contractors

Contract descriptions are located in Part Two. Note that all numbers in this index are preceded by '2-' in the text to indicate Part Two.

Appendix 3
Abbreviations and Acronyms

ANSI	American National Standards Institute
AR	anti-reflective
AR&D	Advanced Research and Development
ASTM	American Society for Testing Materials
Btu	British thermal unit
CM	cylindrical magnetron
CPA	coherent potential approximation
CTD	concentrator technology development
CVD	chemical vapor deposition
CZ	Czochralski crystal growth
DCS	dichlorosilane
DDL/TE	double depletion layer / thermal emission
DOE	Department of Energy
DLTS	deep level transient spectroscopy
EBIC	electron beam-induced current
EELS	electron energy loss spectroscopy
EFG	edge-defined film-fed growth (silicon ribbon process)
EHD	electrohydrodynamic
EMA	ethylene methyl acrylate
EMVJ	etched multiple vertical junction
EPC	electrochemical photovoltaic cells
EPR	ethylene-propylene-rubber (encapsulant for terrestrial modules)
EPSDU	Experimental Process System Development Unit
EPS	electrochemical photocapacitance spectroscopy
ESB	electrostatic bonding
ESCA	electron spectroscopy for chemical analysis
ESGU	experimental sheet growth unit
EVA	ethylene vinyl acetate (encapsulant for terrestrial modules)
FAST	fixed abrasive slicing technique
FSA	flat-plate solar array
FY	fiscal year
GaAs	gallium arsenide
GB	grain boundary
HEM	heat exchanger method
HLE	high/low emitter
HSV	hydrogen saturated vacancy
HTR	high throughput reactor
HWVE	hot-wall vacuum evaporation
ID	internal diameter
IEEE	Institute of Electrical and Electronics Engineers
ISEE	initial system evaluation experiment
JPL	Jet Propulsion Laboratory
kg	kilogram
KVA	kilovolt-amp
kW_p	kilowatt peak (or the amount of electrical energy generated by a solar system at peak daytime exposure to the sun)
LASS	low angle silicon sheet
LSA	low cost solar array
LSC	luminescent solar concentrators
MBE	molecular beam epitaxy
MBS	multiple-blade sawing

MEPSDU	Module Experimental Process System Development Unit
MG	metallurgical grade
MIT/EL	Massachusetts Institute of Technology/Energy Laboratory
MIS	metal insulator semiconductor
MIT/LL	Massachusetts Institute of Technology/Lincoln Laboratory
MT	megaton
MW	megawatt
NASA	National Aeronautics and Space Administration
NASA/ Lewis	National Aeronautics and Space Administration/Lewis Research Center
NEC	National Electrical Code
NMR	nuclear magnetic resonance
NOCT	normal operating cell temperature
NR	nuclear resonance
NWC	Naval Weapons Center
OM-CVD	organo-metallic chemical vapor deposition
PA&I	Planning, Analysis, and Integration
PCU	power-conditioning unit
PDU	process development unit
PEBA	pulsed electron beam annealer
PEC	photoelectrochemical cells
PLE	photoluminescence excitation
PM	planar magnetron
PNBA	poly (n-butylacrylate)
PNL	Pacific Northwest Laboratory
PU	polyether urethane
PV	photovoltaic
PV/T	photovoltaic/thermal
PVTAP	Photovoltaic Transient Analysis Computer Program
Quad	10^{15} Btu
QGBF	quasi-grain boundary free
RD&D	research, development, and demonstration
RF	radio frequency glow discharge
RFP	request for proposal
RSA	reference structure array
RTMS	room temperature molten salts
RTR	ribbon to ribbon (growth technique)
SAMICS	Solar Array Manufacturing Industry Costing Standards
SAMIS	Solar Array Manufacturing Industry Simulation
SEM	scanning electron microscopy
SEMIX	a direct sheet growth technique using polycrystalline sheet material
SERI	Solar Energy Research Institute
SG	semiconductor grade
SIMS	secondary ion mass spectrometry
SNL	Sandia National Laboratory
SOC	silicon on ceramic
SOLERAS	Project agreement for cooperation in the field of solar energy between the United States and Saudi Arabia
SPV	surface photovoltage
T&A	Tests and Applications/Industry Assistance
TCS	trichlorosilane
TD&A	Technology Development and Applications
TEM	transmission electron microscopy
TESS	thermal expansion shear separation
TF	technical feasibility
TR	technical readiness
UCP	ubiquitous crystallization process
UMG	upgraded metallurgical grade Si

Part Two
Fiscal Year 1981
Contract Descriptions

Photovoltaic Advanced Research and Development

The Photovoltaic Advanced Research and Development program is managed by the Solar Energy Research Institute (SERI) under contract to the Department of Energy. Active contracts administrated by SERI in FY 1981 are listed alphabetically by contractor name.

Title:	Advanced Photovoltaic Systems Simulator	**Contract Number:**	1070-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Mrig	**Telephone:**	(303) 231-1807 FTS 327-1807
Contractor:	Abacus Controls, Inc. 80 Reedington Rd. Somerville, NJ 08876		
Principal Investigator:	G. A. O'Sullivan	**Telephone:**	(201) 526-6010
Contract Period of Performance:	**From:** 7/8/81 **To:** 1/15/82		
Project/Area/Task:	Technical Support/Advanced Systems Res.		
Contract Funding:	FY81 $98,222 FY $ FY $ FY $		
Funding Source:	SERI		

The objective of this project is to design and construct an advanced photovoltaic systems simulator for use in characterizing the performance of a simulated total PV system, under outdoor conditions, based on actual advanced PV cell utilization and performance. The system will include a PV cell test bed, high gain amplifier-simulator, power conditioner (up to 10 kW), load profiles, and associated control and data acquisition equipment. In addition, the simulator will be capable of simulating actual cell input parameters as well as synthetic parameters based on research laboratory data. Provisions will also be available for testing exploratory research prototype modules in the field.

Since modules and arrays are not currently available for advanced PV materials, it is the intent of this effort to extrapolate research cell(s) performance up to module/array/system levels and to identify technical issues which may affect current cell research as well as impact the ultimate deployment of advanced PV cell technology systems.

The simulator will also be utilized in verifying advanced system design concepts that have been determined through analytical means. The simulator will be located at the outdoor interim test site at SERI.

Title:	Investigation of Edge Supported Pulling of Silicon Ribbon	**Contract Number:**	1069-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	A. D. Little 20 Acorn Park Cambridge, MA 02140		
Principal Investigator:	E. M. Sachs	**Telephone:**	(617) 864-5770 Ext. 2917
Contract Period of Performance:	**From:** 9/29/81 **To:** 8/29/82		
Project/Area/Task:	High Efficiency/Poly Silicon		
Contract Funding:	FY81 $219,210 FY $ FY $ FY $		
Funding Source:	SERI		

The objective of this program is to investigate the edge supported pulling technique, developed at SERI, with respect to the rapid growth of large areas of silicon ribbon. Growth parameters which are envisioned include 10 cm ribbon width and less than 100 μm ribbon thickness, at a rate of at least 30 cm^2/min. These ribbons will be assessed with respect to their suitability for fabricating efficient solar cells.

Title:	Mechanism of Preparation of Photovoltaic Amorphous Silicon Cells — **Contract Number:** 8041-12
Directing Organization:	Solar Energy Research Institute
Project Engineer:	H. Mahan — **Telephone:** (303) 231-1497
Contractor:	Aerochem Research Laboratories, Inc. P.O. Box 12 Princeton, NJ 08540
Principal Investigator:	H. Calcote — **Telephone:** (609) 921-7070
Contract Period of Performance:	**From:** 9/15/79 **To:** 7/1/81
Project/Area/Task:	Advanced Silicon/Amorphous Materials
Contract Funding:	FY79 $99,948 — FY80 $80,289 — FY81 $-0- — FY $
Funding Source:	SERI — SERI

The objectives of this program are to determine the chemical mechanism by which photovoltaic amorphous silicon films are formed in glow discharges of silane and to identify the relationship between the chemistry of the process and the performance of the resulting devices. The main tool that is used in this study is an ion and molecular beam mass spectrometer. Ions and neutral species are sampled through a small hole in the substrate being coated under a variety of discharge conditions (both dc and rf glow discharges are used). Devices are made under identical conditions for the mass spectrometric study and their performance correlated with the discharge chemistry. To help understand the mechanisms involved, simulation experiments are carried out in which some of the species normally occurring in silane discharges are externally produced and allowed to react. The ultimate goal of the work is to make more efficient solar cells through an understanding of the silicon film formation process.

Title:	Photoelectrochemical Solar Cells Based on d-Band Electrochemistry at Transition Metal Diselenides	**Contract Number:**	9299-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	Ames Lab - USDOE Iowa State University Ames, IA 50011		
Principal Investigator:	Bruce Parkinson	**Telephone:**	FTS 865-7659
Contract Period of Performance:	**From:** 8/15/80 **To:** 6/14/81		
Project/Area/Task:	Polycrystalline Thin Film/Photoelectrochemistry		
Contract Funding:	FY79 \$86,000 FY80 \$112,950 FY81 \$-0- FY \$		
Funding Source:	SERI SERI		

Evaluate and develop the transition metal diselenides WSe_2 and $MoSe_2$ as stable photoelectrodes in liquid junction solar cells.

The approaches which will be used are:

- Grow large single crystals on which device limiting properties can be studied.
- Characterize the photochemical stability of these materials using rotating ring-disc analysis.
- Characterize the transport properties of the layered compounds as a function of impurities and defects.
- Characterize the surface electronic structure in situ by high resolution photo-current measurements.
- Seek to minimize degradation through edge reaction by passivating organics.
- Investigate thin layer electrodes using these materials.

Ames has succeeded in growing high quality WSe_2 and $MoSe_2$ single crystals by the closed space vapor transport technique and has obtained efficiencies of up to 10% and 9.5% respectively in electrochemical photovoltaic cells containing a 2M NaI/0.01MI_2 aqueous electrolyte. Ames has also succeeded in partially passivating surface defects against recombination by the partial intercalation of t-butyl pyridine.

Title:	Conceptual Design Study of the Magnetoplasmadynamic Deposition of Silicon
Contract Number:	9051-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Joseph B. Milstein
Telephone:	(303) 231-7299
Contractor:	AMEX Systems, Inc. 3355 El Segundo Blvd. Hawthorne, CA 90250
Principal Investigator:	Gordon Cann
Telephone:	(714) 751-3660
Contract Period of Performance:	**From:** 5/30/80 **To:** 11/26/80
Project/Area/Task:	High Efficiency/Polycrystalline Silicon
Contract Funding:	FY80 $194,051 FY81 $-0- FY $ FY $
Funding Source:	SERI

The objectives of this program are to evolve the necessary cost-effective equipment designs and define laboratory experiments to prove the deposition of silicon by the magnetoplasmadynamic process. The program will address the feasibility of producing the desired quality of the silicon film by this novel process. The program has been divided into four research tasks: (1) Conceptual Design of the Magnetoplasmadynamic System; (2) Theoretical Studies Relating to the Magnetoplasmadynamic Deposition Process; (3) Development of a Program Plan, and (4) Cost Analysis.

The technical approach planned is to conduct a thorough review of related silicon thin film deposition research to relate results and theories to the magnetoplasmadynamic process, and to predict the film crystallinity expected on the basis of kinetic and thermodynamic considerations. The design of the deposition system and components will emphasize system cost and reliability, and the optimal selection of a liquid, vapor, or solid silicon feed system. The program plan will include the development schedule of a deposition system to demonstrate the feasibility of producing low cost silicon photovoltaic devices by a magnetoplasmadynamic process. A detailed experimental program will be developed with technical milestones for indices of progress. The performance regime being considered for the magnetoplasmadynamic deposition system includes a deposition rate of 1 μm/sec, a deposition area of 1 m^2, operating power of 100 kW, 80% power efficiency, and a monoenergetic particle beam having 10 eV energy per particle.

The theoretical analysis required has been completed and the development of a program plan and cost analysis communicated to SERI.

Title:	Fabrication and Evaluation of Solar Cells	**Contract Number:**	8229-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	S. Deb	**Telephone:**	(303) 231-1105
Contractor:	Applied Solar Energy Corporation 15251 East Don Julian Rd. City of Industry, CA 91746		
Principal Investigator:	P. Illes	**Telephone:**	
Contract Period of Performance:	**From:** 11/8/79 **To:** 9/30/81		
Project/Area/Task:	Solar Cell R&D		
Contract Funding:	FY80 $104,620 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this task is to process and evaluate solar cells from silicon experimental material with various degradation characteristics and to determine means of neutralizing detrimental effects. SERI will provide a wide range of silicon sample types to be processed, ranging from high purity, dislocation-free float zoned material to multi-grained upgraded metallurgical grade silicon on foreign substrates. Approximate resistivity and conductivity type of the material is to be measured prior to processing. Measurements of the cells shall consist of I-V curve, V_{oc}, I_{sc}, fill factor, max. power point, efficiency, dark current and spectral response. Approximately twenty percent of the cells will require advanced processing. The data submitted from the evaluation of the cells shall contain a brief description of unusual outcomes, any difficulties encountered in solar cell processing, and suggestions for processing changes that will optimize photovoltaic performance of the materials.

Title:	Improved Slicing Method for Silicon	**Contract Number:**	9010-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Lee A. Cole	**Telephone:**	(303) 231-1841
Contractor:	Applied Solar Energy Corporation 15251 East Don Julian Rd. City of Industry, CA 91746		
Principal Investigator:	S. I. Soclof	**Telephone:**	(213) 968-6581
Contract Period of Performance:	**From:** 3/15/80 **To:** 3/14/81		
Project/Area/Task:	Compound Semiconductor/High Efficiency Concentrators		
Contract Funding:	FY80 $94,116 FY81 $-0- FY $ FY $		
Funding Source:	SERI		

The objective of this was to explore orientation-dependent-etching (ODE) as an improved slicing method to provide thin silicon slices (25-50 μm) with increased yields (4-10 m^2/kg), and suitable for processing into high efficiency solar cells.

Slicing of silicon by chemically etching narrow slots through silicon slabs was unsuccessful, in that the etching of many narrow slots through the 1.2 mm thick slabs was incomplete. The goal was to produce solar cells from the thin silicon strips. The etch-slicing method presented severe requirements on the materials used to mask against the etchants, on precise angular alignment for opening up lines in these masks, and on the crystallographic perfection of the silicon. In addition to these requirements, the extremely small aspect ratio (i.e., ratio of width to depth) of the slots caused problems in the etching of the slots. The slot width was typically in the 5-20 μm range, and the slot depth required for complete etching-through was >1 mm. A matrix processing sequence was developed for processing strips formed by the ODE process into solar cells.

Major Technical Achievements During the Program

The slicing sequence was demonstrated. This sequence included:

1. Formation of polished (110) oriented silicon slabs.
2. Formation of protective coatings on the two main slab surfaces (combination of SiO_2 and Si_3N_4).
3. Formation of narrow well-aligned slots in the masking layers (aligned within 0.1° of the <111>directions).
4. Orientation-dependent etching through the slots (used 30 M KOH at 85°C mostly); also demonstrated the possibility of controlling etch rates by use of external voltages.
5. Proof of several slice support schemes.

Title:	Computer Modelling of Amorphous Materials for Photovoltaic Conversion	**Contract Number:**	9011-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	T. McMahon	**Telephone:**	(303) 231-7039 FTS 327-7039
Contractor:	Argonne National Laboratory 9700 South Cass Ave. Argonne, IL 60439		
Principal Investigator:	Lester Guttman	**Telephone:**	(312) 972-5514
Contract Period of Performance:	**From:** 10/1/79 **To:** 9/30/81		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY80 $120,000 FY $	FY $	FY $
Funding Source:	SERI		

Because amorphous silicon-hydrogen alloys have shown promise as material for cheap and efficient photovoltaic cells, it is desirable to understand their electronic structure in anticipation of problems that will arise in practice. We construct computer analogues that are faithful representations of the atomic structure of pure amorphous Si, and compute from first principles the electronic wave functions and level energies of examples that contain hydrogen or that are defective in various ways. The results are expected, first, to aid in the interpretation of the effects of hydrogen on electrical resistivity and photoconductivity, and second, to provide guidance in understanding the relation of the transport properties of these materials to their composition, thermal history, and to other parameters of the fabrication process.

The modelling program is being closely integrated with concurrent work on preparation of amorphous silicon films and neutron diffraction studies of their structure (supported by the Division of Basic Energy Sciences).

Title:	Electrodeposited Amorphous Silicon For Solar Cell Applications	**Contract Number:**	8249-1
Directing Organization:	Solar Energy Research Institite		
Project Engineer:	E. Sabisky	**Telephone:**	(303) 231-1483 FTS 327-1483
Contractor:	Battelle Columbus Laboratories 505 King Ave. Columbus, OH 43201		
Principal Investigator:	A. E. Austin	**Telephone:**	(614) 424-5395
Contract Period of Performance:	**From:** 9/15/79 **To:** 10/31/80		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 $297,730 FY80 $308,072	FY81 $-0-	FY $
Funding Source:	DOE SERI		

The overall objective is to evaluate the photovoltaic properties and practicality for attaining a minimum of 10 percent efficiency in solar cells fabricated from electrodeposited amorphous silicon.

The program proposed for the development and the evaluation of electrodeposited, amorphous silicon for thin-film solar cells is divided into four tasks with the following objectives:

Task 1. To develop semiconductor doping of electrodeposited, amorphous silicon with controllable electronic properties of low cost substrates.

Task 2. To determine the physical and electronic properties of doped electrodeposited amorphous silicon.

Task 3. To develop Schottky barrier and p-n junction cells from electrodeposited, amorphous silicon.

Task 4. To evaluate the solar cell efficiency parameters of solar cells of electrodeposited, amorphous silicon.

For the doping of electrodeposited silicon, the electrolytic reduction and codeposition of possible n- and p- type dopants has been investigated. Three dopants, B, Li, and Ga, were found that could be codeposited with the silicon. Annealing was investigated for activation of these dopants in the silicon.

The deposition parameters of temperature and cathode substrates were studied. The hydrogen content of electrodeposited silicon was found to decrease from about 30 atom percent at 35°C with increasing temperature. The deposition onto an aluminum substrate was demonstrated in addition to the prior use of titanium and titanium alloy substrates.

The electronic properties of doped deposits were studied by differential capacitance and Schottky diode measurements. The dopants were found to be activated by annealing in the range of 350 to 400°C. This was also found to be the range for the start of hydrogen release from the silicon. Both n- and p-type doping have been demonstrated.

Title:	Stability of Cadmium Sulfide/ Copper Sulfide Solar Cells	**Contract Number:**	9169-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Battelle-Columbus Laboratories 505 King Ave. Columbus, OH 43201		
Principal Investigator:	Gerald T. Noel	**Telephone:**	(614) 424-7481
Contract Period of Performance:	**From:** 8/12/80 **To:** 8/11/82		
Project/Area/Task:	Compound Semiconductors/Cadmium Sulfide		
Contract Funding:	FY80 $368,061 FY81 $314,300 FY $ FY $		
Funding Source:	SERI SERI		

The general objective of this project is to determine the viability of fabricating high efficiency Cu_2S/CdS and CdS/$CuInSe_2$ solar cells with operational lifetimes of the order of 20 years or more. Specific objectives are: (1) identify major intrinsic and extrinsic degradation modes; (2) determine physical, chemical, and mechanical processes which lead to device degradation; (3) make projections on the performance of cells over a 20 year period; (4) assess the potential for producing stable low-cost cells.

Cu_2S/CdS cells have undergone a matrix stress test in an argon ambient designed to address the above objectives. It includes: (1) device characterization by current-voltage and capacitance-voltage measurements, laser scans, etc.; (2) material analysis by SEM, SIMS, Auger, etc.; (3) stress tests under various temperatures, ambients, light intensity, electrical loading, and mechanical flexing.

Preliminary results indicate that the degradation in Cu_2S/CdS cells may be reversible under normal operating cycles. A significant portion of observed degradation appears to be due to photochemical changes that can be reversed by removing the cells from light. Open circuit voltage can be restored to full initial values after several hours in the dark. Partial recovery of I_{sc} in cells can be seen after several days in the dark. In general, cells in roof top tests showed less degradation than cells exposed to continuous illumination.

Title:	Thin Film Optical Evaluation	**Contract Number:**	1105-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Larry Kazmerski	**Telephone:**	(303) 231-1115
Contractor:	Battelle Pacific Northwest Laboratory Battelle Blvd. Richland, WA 99352		
Principal Investigator:	John Hartman	**Telephone:**	
Contract Period of Performance:	**From:** 7/1/81 **To:** 3/31/82		
Project/Area/Task:	Measurements and Evaluation		
Contract Funding:	FY81 $63,000 FY $	FY $	FY $
Funding Source:	SERI		

1. Examination and documentation of the pertinent literature.
2. Documentation of the theoretical basis for sample analysis with spectrophotometric data, including an emphasis on the key physical principles involved and adequate references to more detailed discussions of background material.
3. Development of theoretical models and equations for reduction of spectrophotometric data taken on the following types of samples:
   a. bare substrates
   b. substrates with a single film
   c. substrates with two films.

The materials to be studied are restricted to those with non-zero reflectance and transmission values. The study of opaque materials may be considered in a possible future contract regarding the interpretation of ellipsometric data, which is needed, in addition to spectrophotometric data, to characterize these materials.

4. Development of computer codes for the equations.
5. Development of techniques for accurate (to within 1%) reflectance measurements on all solid samples, including finished devices.
6. Empirical verification of the computer codes and reflectance measurement techniques with the use of well-characterized samples, to be supplied by PNL. SERI M&E staff may, at their discretion and in coordination with PNL, supply additional samples for use in the empirical verification efforts.
7. Identification of the potential shortcomings of the procedures for material analysis.
8. Identification of measurement procedures critical to data accuracy and repeatability.
9. Assisting SERI (M&E lab) staff in preparing a technical report, which will be written so that owners of models of spectrophotometers and computers different than those owned by PNL and SERI will be able to use the computer codes and procedures given with a minimum of work.

Title:	The Evaluation of Critical Materials for Photovoltaic Cells	**Contract Number:**	8137-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	R. DeBlasio	**Telephone:**	(303) 231-1286 FTS 327-1286
Contractor:	Battelle Pacific Northwest Laboratory P.O. Box 999 Richland, WA 99352		
Principal Investigator:	R. L. Watts	**Telephone:**	(509) 942-4348 FTS 444-4348
Contract Period of Performance:	**From:** 5/15/79 **To:** 3/14/81		
Project/Area/Task:	Technical Support/Availability of Materials		
Contract Funding:	FY79 $194,130 FY80 $75,000 FY81 $2,000 FY $		
Funding Source:	SERI SERI SERI		

The objective of this effort is to review potential supply, production, and economic constraints of material technologies supported by the AR&D program including sensitivity and analysis of technology maturity, commercialization scenarios, and key material supply and production factors. Device technology manufacturing processes are characterized in terms of material requirements. A deployment scenario is postulated to calculate material demand over time and compare against set criteria (resources, import fractions, capacity growth rates, cost, etc.) for potential supply problems. Results are analyzed and detailed investigations are recommended as needed.

A report has been published, The Evaluation of Critical Materials for Five Advanced Design PV Cells with an Assessment of Gallium and Indium, R. L. Watts et al., PNL-3319, May 1980, covering work performed with FY 1979 funds, and is available from NTIS. The five cells examined were polycrystalline silicon, amorphous silicon, cadmium sulfide/copper sulfide, polycrystalline gallium arsenide, and an advanced III-V multijunction concentrator. Five additional technologies were investigated in FY 1980 and FY 1981. These are indium phosphide/cadmium sulfide, cadmium telluride, zinc phosphide, cadmium sulfide/copper indium selenide and a photoelectrochemical device, cadmium (telluride) selenide. A report has been published, Evaluation of Critical Materials In Five Additional Advance Design Photovoltaic Cells, S. A. Smith et al., PNL-3710, February 1981, covering work performed with FY 1980 and FY 1981 funds; it is available from NTIS.

Title:	Photovoltaics: Spectral Response of Solar Cells		**Contract Number:** 9235-1		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	Larry Kazmerski		**Telephone:** (303) 231-1115		
Contractor:	Battelle Pacific Northwest Laboratory P.O. Box 999 Richland, WA 99352				
Principal Investigator:	Dr. J. Hartman		**Telephone:** (509) 375-2101		
Contract Period of Performance:	**From:** 9/1/80 **To:** 12/31/81				
Project/Area/Task:	Technical Support/Measurement and Evaluation				
Contract Funding:	FY80 $149,996	FY81 $37,000	FY $		FY $
Funding Source:	SERI	SERI			

The purpose of this effort is to examine problems associated with the reliable evaluation of photovoltaic cell response of advanced, thin film photovoltaic solar cells with the ultimate goal of developing a standardized PV energy conversion efficiency measurement technique that does not require the use of representative production lot standard solar cells.

Battelle will form a technical committee to review technical approaches to the problem and to serve in an advisory capacity for the duration of the program. The technical committee shall be comprised of experts from various PV materials and device categories who are familiar with the problems associated with the technical effort. The candidates proposed for the technical committee shall be first reviewed and approved by SERI prior to formalization of the committee. At least one member of the SERI technical staff shall be a member of the technical committee.

Battelle will also perform examinations of experimental solar cells provided by SERI and other cooperating SERI Subcontractors to assess the technical problems examined above.

A detailed program plan summarizing the technical problems, the methodology designed to resolve the problems, and progress toward an ultimate solution will be written. The program plan shall be prepared by the end of the first contract quarter for review and approval by SERI. The technical committee shall act as an advisor in the program plan approval process.

Title:	Module Optimization Methodology for Advanced PV Cells and Devices	**Contract Number:**	1064-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Laxmi Mrig	**Telephone:**	(303) 231-7178
Contractor:	BDM Corporation 1801 Randolph Rd, S.E. Albuquerque, NM 87106		
Principal Investigator:		**Telephone:**	
Contract Period of Performance:	**From:** 5/12/81 **To:** 2/28/82		
Project/Area/Task:	Analysis and Support		
Contract Funding:	FY81 $64,100 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this study is to develop a methodology for optimizing cost/performance and identifying key technical issues of advanced terrestrial PV modules for different applications. The methodology developed will be generic in nature and applicable for various advanced PV cell and device configurations and will provide a basis for comparative and tradeoff performance and cost studies.

A computer code will be developed based on the methodology, and the code will be installed on the SERI CDC 7600 computer system.

Title:	Design Analysis of Advanced Photovoltaic Technologies	**Contract Number:**	1228-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Mrig	**Telephone:**	(303) 231-1807
Contractor:	BDM Corporation 1801 Randolph Rd., S.E. Albuquerque, NM 87106		
Principal Investigator:	M. Semmens	**Telephone:**	(505) 848-5000
Contract Period of Performance:	**From:** 5/12/81 **To:** 2/28/82		
Project/Area/Task:	Technical Support/Advanced Systems Research		
Contract Funding:	FY81 $87,284 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this project is to perform preliminary exploratory research and design analysis of advanced photovoltaic materials and cell technologies for adaptation to present and future module/system designs and utilization. This analysis will include: (i) amorphous silicon; (ii) polycrystalline silicon; (iii) cadmium sulfide; and (iv) gallium arsenide cell technologies.

The approach taken for the analysis will be to develop baseline conceptual module and system designs for each advanced PV cell technology given above, based on present and projected cell characteristics, parameters, and processes. Module and system performance will be evaluated and analyzed using computer techniques such as PVTAP and SOLCEL II. System performance, safety, and reliability analysis will be performed for normal and anticipated worst case conditions. Estimates of module and system cost will be determined and evaluated for optimum conditions.

As part of this project the Photovoltaic Transient Analysis Computer Program (PVTAP) will be adapted and installed at SERI on the CDC7600 computer system.

Preliminary design criteria and guidelines will be documented identifying key areas of module and systems adaptation technical issues as related to present and future advanced cell research.

Title:	Cadmium Sulfide/Copper Ternary
Contract Number:	8021-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Allen Hermann
Telephone:	(303) 231-1311
Contractor:	Boeing Aerospace Company P.O. Box 3999 M/S 88-43 Seattle, WA 98124
Principal Investigator:	Reid Mickelsen
Telephone:	(206) 773-1074
Contract Period of Performance:	**From:** 9/30/77 **To:** 8/25/82
Project/Area/Task:	Compound Semiconductors/Cadmium Sulfide

Contract Funding:	FY76 $177,500	FY78 $177,500	FY79 $185,760	FY80 $521,023
Funding Source:	ERDA	DOE	SERI	SERI
Contract Funding:	FY81 $250,000			
Funding Source:	SERI			

The objective of this program is to conduct research leading to the development of a large area, low cost, stable, polycrystalline thin film photovoltaic solar cell of 10% efficiency based upon the CdS/$CuInSe_2$ material system. The technical approach is to improve performance and fabrication economics of earlier developed cells produced by vacuum evaporation techniques (simultaneous elemental evaporation for $CuInSe_2$) onto inexpensive substrates. Specific research tasks include: (1) improving cell performance by optimizing deposition process, grid geometry, and AR (anti-reflection) coating; (2) developing a cell model based on experimental analysis of cell parameters; (3) exploring the effects of alternate structures involving (Cd,Zn)S; (4) studying the effects of heat treatment; (5) initiating a stability study; (6) designing and implementing a large area cell fabrication process.

To date, cells with efficiencies between 9-10% with an AR coating have been fabricated on a repeatable basis. Cells as large as 8 cm^2 with $\eta = 7.3\%$ have been made. Effects of heat treatment ambients have been established. Short circuit current increased independent of ambient while open circuit voltage and fill factor requires the presence of oxygen for improvements. Uncoated cells stored in room ambient for one year showed no signs of significant degradation. Similar cells exposed to constant illumination (simulated AM1) and biased in open circuit and near maximum power point have shown no degradation after 3000 hours in room ambients.

Title:	Cadmium Sulfide/Copper Selenide Cell Research	**Contract Number:**	9216-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Boeing Aerospace Company Electronics Technology P.O. Box 3999 Seattle, WA 98124		
Principal Investigator:	Reid Mickelson	**Telephone:**	(206) 773-1074
Contract Period of Performance:	**From:** 5/1/79 **To:** 9/29/82		
Project/Area/Task:	Compound Semiconductor/Emerging Materials		
Contract Funding:	FY79 \$77,869	FY80 \$77,581	FY81 \$76,609 FY \$
Funding Source:	DOE	SERI	SERI

The purpose of this program is to continue investigation of the feasibility of using $Cu_{2-x}Se$ as a semiconductor material for the low cost production of photovoltaic solar cells. These cells would be formed as heterojunctions with CdS films. Both the selenide and sulfide films are deposited by vacuum evaporation methods onto inexpensive substrates which would lead to the possibility of large scale, low-cost cell production. The optical, electrical and structural properties of $Cu_{2-x}Se$ have been analyzed and found consistent with development of 10% efficient thin film cells.

To meet the described objectives, research efforts are concentrating on the following:

- Continuation of the development and characterization of controllably doped evaporated p-type $Cu_{2-x}Se$ films;
- Continuation of the development and characterization of low resistance ohmic contacts to p-type evaporated $Cu_{2-x}Se$ films;
- Development and characterization of greater than 1 cm^2 thin film evaporated $CdS/Cu_{2-x}Se$ heterojunctions with analysis of the mechanisms which control the photocurrent and junction rectification and limit the photovoltaic efficiency; and
- Preliminary assessment of the stability of $CdS/Cu_{2-x}Se$ devices.

Improved control during film growth has allowed lower substrate temperatures (160°C). In addition, by using a higher temperature CdS source, CdS film resistivities down to 3 ohm-cm have been achieved. CdS/Cu_2Se solar cells have been fabricated with 1 cm^2 total area, efficiencies of 4.25%, V_{oc} = 457 mV, J_{sc} = 14.43 ma/cm^2, and FF = 0.64.

Title:	Advanced Amorphous Materials for Photovoltaic Conversion		**Contract Number:** 9055-1	
Directing Organization:	Solar Energy Research Institute			
Project Engineer:	E. Sabisky		**Telephone:** (303) 231-1483 FTS 327-1483	
Contractor:	Brookhaven National Laboratory Dept. of Energy and Environment Upton, Long Island, NY 11973			
Principal Investigator:	Richard Griffith		**Telephone:** (516) 345-3544	
Contract Period of Performance:	**From:** 10/1/78 **To:** 7/30/82			
Project/Area/Task:	Advanced Silicon/Amorphous Materials			
Contract Funding:	FY79 $180,000	FY80 $520,000	FY81 $-0-	FY $
Funding Source:	DOE	SERI	SERI	

The commercial feasibility of a-Si:H photovoltaic conversion depends on the attainment of reasonable solar cell efficiencies (5-10%) with large-area devices. Whereas sizable mobility-lifetime ($\mu\tau$) products are found for majority-carrier electrons in a-Si:H alloys, minority-carrier hole transport so far limits device performance at any stage of engineering sophistication. It has been shown that synergistic effects of nitrogen and oxygen impurities in the plasma give rise to: (i) enhanced photoconductivity and n-type doping of plasma-deposited a-Si:(H,O,N,...) alloys, but (ii) dramatically reduced efficiencies of MIS and p-i-n solar cells fabricated with such alloys. Impurity incorporation particularly degrades the short-circuit current density J_{sc} owing to a collapsed depletion region and to a significant reduction of the $\mu\tau$ product for minority-carrier holes. Therefore, the role of trace impurities in controlling optoelectronic film quality and device performance of a-Si:H alloys as a function of plasma processing conditions will continue to be investigated. This methodology will also be applied to studies of newer amorphous semiconductor (a-SiC) materials, such as a-Si:(F,H) and other alloys, in which recombination centers are passivated by hydrogenation and/or halogenation. Diagnostic a-SiC solar cells will be fabricated, and the diode and photovoltaic parameters will be determined. The objective of the task is to improve minority-carrier transport (and the fill factor) so that conversion efficiencies may be raised for a-SiC materials.

Title:	Electrochemical Photovoltaic Cells	**Contract Number:**	8312-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	Brooklyn College of CUNY Bedford Avenue and Avenue H Brooklyn, NY 11210		
Principal Investigator:	Micha Tomkiewicz	**Telephone:**	(212) 780-5357
Contract Period of Performance:	**From:** 9/15/79 **To:** 4/30/82		
Project/Area/Task:	Polycrystalline Thin Film/Photoelectrochemistry		
Contract Funding:	FY79 $152,628	FY80 $134,177	FY81 $294,961 FY $
Funding Source:	SERI	SERI	SERI

The objective of this contract is to characterize and develop high efficiency polycrystalline n-CdSe electrochemical photovoltaic cell devices incorporating aqueous electrolytes and to develop three electrode photoelectrochemical storage cells based on CdSe photoanodes.

The approaches which will be used are:

- Grow polycrystalline thin films of n-type CdSe on metal substrates using the electrodeposition technique.
- Characterize the electrodeposited CdSe films using electrolyte-electroreflectance spectroscopy and network analysis techniques.
- Further characterize CdSe films as photoanodes in electrochemical photovoltaic cells.
- Develop high efficiency electrochemical photovoltaic devices through improvements in the CdSe film quality and improvements in device configuration.
- Design and construct three electrode storage cells using thin film CdSe photoanodes and exploring the use of various membrane and storage electrode candidates.

Brooklyn College has currently constructed experimental thin film CdSe electrochemical photovoltaic cells exhibiting over 6% efficiency using a $S/S^{-2}/OH^{-}$ aqueous electrolyte and Ni counterelectrodes. Electrodeposited CdSe films have been characterized using electrolyte-electroreflectance spectroscopy and impedance measurements. Various membranes as candidates for the three electrode storage cell have been characterized and new storage electrode systems are in the process of being developed.

Title:	Cadmium Sulfide/Mixed Copper Ternary Semiconductor Heterojunction Solar Cell Research			**Contract Number:** 8012-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	A. Hermann			**Telephone:** (303) 231-1311			
Contractor:	Brown University Division of Engineering Providence, RI 02192						
Principal Investigator:	J. J. Loferski			**Telephone:** (401) 863-2761			
Contract Period of Performance:	**From:** 9/30/77 **To:** 3/1/82						
Project/Area/Task:	Cadmium Sulfide						
Contract Funding:	FY78 $224,000	FY79	$240,643	FY80	$340,049	FY81	$168,636
Funding Source:	DOE	SERI		SERI		SERI	

The objectives of the research are to develop cadmium sulfide/copper ternary heterojunction solar cells which can be manufactured reproducibly with air mass-1 conversion efficiency of no less than 8% as measured between 20°C and 30°C over cell areas of at least 4 cm^2. Maximum electrical output degradation is to be 5% over twenty years.

The proposed continuation includes the following tasks: (1) fabrication of thin film cells by evaporation and sputtering using selected materials of ternary, combinations of Cu, In, Se; (2) material diagnostics and characterization; (3) device modeling; (4) system modeling; and (5) fabrication and delivery of representative cells.

Professor Loferski and his colleagues primarily emphasize $CuInSe_2$/CdS device structures. They have succeeded in preparing target materials from which thin film cells are to be fabricated either by evaporation and sputtering and up to 5% efficiency has been demonstrated. A small area cell fabricated from evaporated CdS film on sputtered CuIn has shown 5% conversion efficiency without AR coating. The effort is now concentrated on the fabrication of a thin film and polycrystalline cell of this type of material.

Title:	Efficient Luminescent Solar Concentrators			**Contract Number:**	1262-1		
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	J. Benner			**Telephone:**	(303) 231-1396		
Contractor:	California Institute of Technology Pasadena, CA 91103						
Principal Investigator:	Ahmed Zewail			**Telephone:**	(213) 795-6811 Ext.2537		
Contract Period of Performance:	**From:** 5/15/79 **To:** 1/14/82						
Project/Area/Task:	Innovative Concepts						
Contract Funding:	FY79 $144,116	FY80 $126,604		FY81	$43,108	FY	$
Funding Source:	SERI	SERI		SERI			

The ultimate objective of this research is to produce high efficiency (>8%) Luminescent Solar Concentrators. Specific areas to be investigated include energy transfer between dye ensembles, relaxation for excitation within the same dye ensemble, Stokes-shift characterization to minimize self-absorption, and theoretical limiting efficiency studies from a thermodynamic standpoint.

Six tasks have been identified:

a. Survey of the physical characteristics of the constituents used in LSC devices.

b. Study of inter-dye ensemble energy transfer in the steady-state as a function of dye concentration.

c. Measurement of relaxation times for dyes using a passively mode-locked pulse laser.

d. Observation of intra-dye energy exchange rates as a function of excitation energy and matrix material temperature.

e. Building of several concentrators of novel design, consisting of dyes in solution between two glass plates.

f. Study of photodegration rates of dyes in a variety of hosts.

A computer data acquisition system has been interfaced with two automated spectrometers allowing routing gathering and storage of emission and excitation spectra of dye molecules. Multi-dye systems have been studied using this set-up. Concentration dependences have shown that at low concentrations (less than 0.0005 molar) energy transfer between ensembles does not compete successfully with simple fluorescences. Dye relaxation times have also been measured, and the "freezing" of rotational relaxation in rigid media has been observed. Directional properties of transition moments in the dye molecules have also been studied. Self-absorption has been shown to be a dominant effect and its impact has been shown to be predicted reasonably well from the theoretical formalism developed. Liquid hosts have been investigated, and dye lifetimes have been measured to be anomalously long. Half-lives approaching 100 days have been established in actual outdoor weathering tests.

Title: Grain Growth in Polycrystalline Silicon
Contract Number: 9112-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Thomas Surek
Telephone: (303) 231-1371
Contractor: Case Western Reserve University
Department of Metallurgy
Cleveland, OH 44106
Principal Investigator: G. E. Welsch
Telephone: (216) 268-4236
Contract Period of Performance: **From:** 1/15/80 **To:** 10/15/80
Project/Area/Task: High Efficiency/Polycrystalline Silicon
Contract Funding: FY80 $24,800 FY81 $-0- FY $ FY $
Funding Source: SERI

The objective of this investigation is to gain information on grain growth of polycrystalline silicon in recrystallization heat treatments.

The approach to the research is to use a fine grained (0.1 to 1 μm) starting material which had been produced by sintering of amorphous silicon powder, and to subject it to recrystallization heat treatments just below the melting temperature (T_m) of silicon.

The studies to date have demonstrated that recrystallization heat treatments at 1380°C (T_m = 1410°C) produced negligibly small grain growth even after times as long as 100 min. The resulting grain size, as measured from TEM micrographs, was 0.2 to 1 μm. However, the density of twin boundaries within the grains was substantially reduced by the high temperature heat treatment. The reasons for the non-recrystallization behavior are not understood, but are thought to be related to the presence of oxide on the surface of the particles.

Title: Research on PV Devices Using a-Si Produced by CVD From Higher Order Silanes
Contract Number: 1242-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Frank Jeffrey
Telephone: (303) 231-7036
Contractor: Chronar Corporation
Princeton, NJ
Principal Investigator: Dr. Vic Dalal
Telephone: (609) 587-8000
Contract Period of Performance: **From:** 8/1/81 **To:** 7/31/82
Project/Area/Task: Amorphous Materials
Contract Funding: FY81 $180,200 FY $ FY $ FY $
Funding Source: SERI

The purpose of this project is to investigate the use of CVD of a-Si:H from disilane to produce solar cells. The process is attractive because of its compatability with large scale manufacturing. The initial work will be a study of the suitability of the CVD material based on Schottky barrier diode cells.

Title:	Investigation of Efficiency Loss Mechanisms in CdS/Cu_2S and Related Thin Film Solar Cells	**Contract Number:**	9217-01
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Clarkson College of Technology Electrical Engineering Department Potsdam, NY 13676		
Principal Investigator:	N. K. Annamalai	**Telephone:**	(315) 268-2349
Contract Period of Performance:	**From:** 5/3/79 **To:** 9/30/81		
Project/Area/Task:	Compound Semiconductor/Cadmium Sulfide		
Contract Funding:	FY79 \$99,675 FY80 \$76,793 FY81 \$2,000 FY \$		
Funding Source:	DOE SERI SERI		

The objective of this project is to obtain a better understanding of those mechanisms which cause efficiency losses in polycrystalline, thin-film CdS/Cu_2S and related solar cells. Special attention is being placed on two specific mechanisms, these being oxidation and interdiffusion.

To meet the desired objective, four tasks have been identified:

1. Investigate oxidation and the interdiffusion of Cu and Cd in CdS/Cu_xS solar cells, and their relation to efficiency and stability of cell performance.
2. Produce CdS/Cu_xS cells (with x being near 1.995) by sequential evaporation of the two constituent active layers without breaking the vacuum.
3. Characterize films and cells produced by (a) evaporation, and (b) the conventional wet-dip process. These will be compared, especially with regard to Cu oxidation and interdiffusion. Various measurement techniques will be used including capacitance, resistivity, I-V data, Hall effect, spectral response, and ion-scattering spectroscopy.
4. Perform accelerated degradation experiments and relate data to Cu oxidation and to interdiffusion identified by characterization and performance data.

Cells fabricated by the sequential evaporation process have demonstrated efficiencies between 1% and 2%. Interdiffusion of Cu and Cd have been observed by Auger spectroscopy studies on heat treated cells. Resistivity and Hall effect measurements have been made on heat treated Cu_xS films. Photoconductive decay in CdS films has been studied. Deep trap levels in CdS have been identified by capacitance versus voltage measurements on Cu_xS/CdS cells.

Title:	Transient Measurement Research	**Contract Number:**	1237-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Larry Kazmerski	**Telephone:**	(303) 231-1115
Contractor:	Colorado State University Fort Collins, CO 80221		
Principal Investigator:	J. Sites	**Telephone:**	
Contract Period of Performance:	**From:** 5/18/81 **To:** 12/4/81		
Project/Area/Task:	Measurements and Evaluation		
Contract Funding:	FY81 \$26,600 FY \$ FY \$ FY \$		
Funding Source:	SERI		

Research and development on heterojunction solar cells is being performed to examine the deviation from ideal diode behavior. Specifically, the I-V terminal characteristics and C-V measurements are being evaluated on several device structures of current interest ($CdS/CuInSe_2$, GaAlAs/GaAs). A model is under development which accounts for the light and dark characteristics of these devices and predicts the limitation in reaching the ultimate cell efficiencies. Device structures are supplied by SERI subcontractors and the PV Device and Measurements Branch.

Title: Novel Concepts in Electrochemical Solar Cells — **Contract Number:** 9272-1
Directing Organization: Solar Energy Research Institute
Project Engineer: William Wallace — **Telephone:** (303) 231-1380
Contractor: Colorado State University
Fort Collins, CO 80221
Principal Investigator: Rajeshwar Krishnan — **Telephone:** (303) 491-8235
Contract Period of Performance: From: 5/1/79 To: 9/30/81
Project/Area/Task: Polycrystalline Thin Film/Photoelectrochemistry

Contract Funding:	FY79 $198,225	FY80 $182,198	FY81 $9,990	FY $
Funding Source:	DOE	SERI	SERI	

The objective of this program is threefold: (1) to characterize the electrochemical and photoelectrochemical behavior of semiconductor photoanode materials in various room temperature conducting molten salt electrolytes in order to test the feasibility of using molten salt systems to promote the long-term stability of photoelectrochemical cells; (2) the deposition of II-VI thin film materials by sputtering and subsequent admittance measurement techniques to extract more accurate Mott-Schottky parameters and to provide a more detailed understanding of the physics and chemistry of the semiconductor/electrolyte interface.

Admittance measurements using the automated technique developed in this laboratory were conducted on the n-GaAs/aqueous electrolyte interface. The aspects studies include variation in the surface-state densities with electrolyte pH and the presence of certain ions (e.g., Ru^{3+}) in the electrolyte. Similar studies were conducted on the n-InP/$AlCl_3$-BPC and n-GaP/$AlCl_3$-BPC interfaces, and a comprehensive PEC characterization of the former system was carried out.

A simple, unified model to explain surface state mediated charge transfer in PEC systems has been developed and compared with experimental data on the n-GaAs/$AlCl_3$-BPC and n-CdSe/polysulfide PEC systems.

Title: Fundamental Studies of Polycrystalline Silicon for Photovoltaic Applications — **Contract Number:** 1272-1
Directing Organization: Solar Energy Research Institute
Project Engineer: R. W. Hardy — **Telephone:** (303) 231-1482
Contractor: Columbia University
Dept. of Electrical Engineering
New York, NY 10027
Principal Investigator: E. S. Yang — **Telephone:** (212) 280-3120
Contract Period of Performance: From: 1/1/79 To: 8/31/81
Project/Area/Task: High Efficiency/Polycrystalline Silicon

Contract Funding:	FY79 $232,311	FY80 $149,970	FY81 $119,199	FY $
Funding Source:	DOE	SERI	SERI	

The objectives of this work include: (1) increased understanding of grain boundaries; (2) more accurate modeling of MS, IL, MIS, and p/n solar cells; (3) definition of instability and degradation mechanisms; and (4) improved solar cell design for efficiency and stability.

A grain boundary model containing only two adjustable parameters has been developed which fits laser beam induced current (LBIC) data obtained using a He laser (6328 Å). The model has been extended to include effects of carrier transport and recombination through traps.

Title:	Fundamental Studies of M-S and MIS Solar Cells on Polycrystalline Silicon	**Contract Number:**	9226-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Simon Tsuo	**Telephone:**	(303) 231-7682
Contractor:	Columbia University Dept. of Electrical Engineering and Comp. Science 1312 Mudd Building New York, NY 10027		
Principal Investigator:	E. S. Yang	**Telephone:**	(212) 280-3120
Contract Period of Performance:	**From:** 9/1/80 **To:** 8/31/81		
Project/Area/Task:	Polycrystalline Silicon		
Contract Funding:	FY80 $149,970 FY $	FY $	FY $
Funding Source:	SERI		

The purpose of this contract is to investigate the fundamental properties of M-S and MIS Schottky-Barrier solar cells fabricated on polycrystalline silicon substrates.

A new technique, in which the open-circuit voltage is plotted vs. short-circuit current at varying illumination intensity, is found to provide a better description of the solar cells when the n-value reflects the electrostatic potential drop across the interface layer in MIS structures. The majority carrier MIS cell (e.g., Au-SiO_2-nSi) has been found to be less sensitive to the parameters of the oxide layer, but to have a somewhat lower efficiency than the minority-carrier cell (e.g., Al-SiO_2pSi). The tunneling barriers for the holes are found to be consistently much large than those for electrons.

Experimental I-V and C-V characteristics of Schottky diodes with variable grain sizes have been measured. Analyses of the data indicate that the transport may be electrode-limited or bulk-limited depending on the average grain size. In addition, minority carrier injection dominates the dark current for sufficiently small grain size and large grain-boundary (GB) mismatch angle. The minority carrier current shows an exp (qV/nKT) dependence with n values of unity, of 2 or 4/3 depending upon the grain boundary barrier height and the region of applied bias voltage.

Al-poly-Si Schottky-barrier diodes have been fabricated on Wacker polycrystalline wafers. By examining the surface features of diodes on the same substrate, it was found that high-angle grain boundaries, distinguished by different etch pits on the two adjacent grains, have a strong influence on the current-voltage and low-frequency capacitance characteristics of the diode. On the other hand, twin boundaries, with similar etch pits on both sides of the boundary, have little effect on the current transport and capacitance with the exception that the Schottky-barrier height is consistently higher than the corresponding single-crystal diodes.

Finally, a technique was developed for forming Schottky barriers with high barrier height (0.93eV) and low reverse saturation current (10^{-5} A/cm^2). This structure has the potential of high open-circuit voltage and efficiency.

Title: Investigation of Electronic Properties of Polycrystalline GaAs
Contract Number: 9316-1
Directing Organization: Solar Energy Research Institute
Project Engineer: J. Benner
Telephone: (303) 231-1396
Contractor: Cornell University
Ithaca, NY 14853
Principal Investigator: Ken Wagner
Telephone: (607) 252-3703
Contract Period of Performance: **From:** 9/29/80 **To:** 12/31/81
Project/Area/Task: Thin Film Gallium Arsenide
Contract Funding: FY80 $124,351 FY81 $-0- FY $ FY $
Funding Source: SERI

The study of the electronic properties of polycrystalline GaAs is intended to identify the mechanisms causing the low V_{oc} and fill factor observed in solar cells. Using data obtained by spatially resolved measurements, diffusion lengths, C-V analysis and DLTS, device modeling will be employed to improve the understanding of the capabilities and limitations of thin film polycrystalline GaAs solar cells.

Title: Low-Cost Silicon Substrates by Directional Solidification
Contract Number: 9171-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Joseph B. Milstein
Telephone: (303) 231-7299
Contractor: Crystal Systems, Inc.
35 Congress St.
Salem, MA 01970
Principal Investigator: Chandra P. Khattak
Telephone: (617) 745-0088
Contract Period of Performance: **From:** 3/1/80 **To:** 2/28/81
Project/Area/Task: High Efficiency/Polycrystalline Silicon
Contract Funding: FY79 $227,000 FY81 $-0- FY $ FY $
Funding Source: SERI

The objective of this work is to identify and develop low-cost processes for fabricating large grain-size polycrystalline silicon substrates. Specifically, the studies will involve the directional solidification of silicon ingots using the Heat Exchanger Method (HEM). The investigations will examine the use of metallurgical grade (MG) silicon as the feedstock for the casting process, and will study both prior and in situ purifications to obtain high purity, low-cost polycrystalline silicon substrates.

All known suppliers of MG silicon have been contacted. The samples received have been analyzed by emission spectroscopic techniques. The commercially available silicon has been found to contain between 98% and 99% silicon. Single crystal structure in 15 cm cube ingots was produced by HEM from all sources of MG silicon tested. This is believed to be the first time a single crystal structure has been produced from MG silicon by a single directional solidification. The major contaminants existed as oxides and carbides which form particulates in molten silicon and generally float on the surface of the melt. After directional solidification most of the impurities, except for aluminum and iron, were reduced below the detectibility limits of spark source emission spectrographic analysis. The resistivity of HEM solidified MG silicon was in the range of 0.03 to 0.08Ω-cm. Epitaxial solar cells fabricated using this silicon substrate have shown AM1 conversion efficiencies up to 11.8%, about 90% of the control cells made from high-purity CZ silicon substrates.

Various refining operations, such as vacuum melting and slagging, have been carried out in the HEM furnace. The effect of holding time and superheat temperatures on the volatilization of high vapor pressure impurities has also been studied.

Title:	Determination of Minority Carrier Lifetimes of Carriers in Direct Bandgap Photovoltaic Semiconductors			**Contract Number:** 1224-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	Larry Kazmerski			**Telephone:** (303) 231-1115			
Contractor:	Denver University Denver, CO 80210						
Principal Investigator:	Robert Amic			**Telephone:**			
Contract Period of Performance:	**From:** 4/1/81 **To:** 1/5/82						
Project/Area/Task:	Research and Development						
Contract Funding:	FY81 $9,479	FY	$	FY	$	FY	$
Funding Source:	SERI						

The purpose of this program is to develop and implement a picosecond laser-based measurement system to determine the minority-carrier lifetime of carriers in direct bandgap photovoltaic semiconductors. These materials usually have lifetimes in the nanosecond or less range, and the determination of this fundamental semiconductor parameter is important for material and device quality indications. The method involves measuring the photoluminescent decay of picosecond laser pulses (of appropriate wavelength) using fast photon-counting techniques. Lifetimes in GaAs, InP, and CdS will be evaluated initially.

Title:	Test Method Development			**Contract Number:** 9407-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	P. Longrigg			**Telephone:** (303) 231-1183			
Contractor:	DSET Labs Box 1850 Black Canyon Stage Phoenix, AZ 85029						
Principal Investigator:	R. Whittaker			**Telephone:** (602) 465-7356			
Contract Period of Performance:	**From:** 11/3/80 **To:** 12/15/81						
Project/Area/Task:	Performance Criteria/Test Methods						
Contract Funding:	FY81 $199,194	FY	$	FY	$	FY	$
Funding Source:	SERI						

Under this contract specific test method development assignments include:

- Global Calibration of Reference Cells
- Spectral Irradiance Measurements of Solar Simulators
- Assessment of Methods for Determining I-V Curve Characteristics
- Verification of NOCT Test Method

Work has been completed on the spectral irradiance measurements for continuous and pulsed simulators; the latter includes spatial and temporal stability characteristics. The global calibration method has been developed and current work is directed at refinement of the limits of the technique. This work has included liaison with the CEC laboratory in Ispin, Italy, to resolve differences in technique.

Title:	Preparation and Characterization of Hydrogenated a-Si Films Produced by Ion Plating and Hydrogenated a-B Films Produced by Glow Discharge Decomposition — **Contract Number:** 9054-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	F. Jeffrey — **Telephone:** (303) 231-7036
Contractor:	Duke University Durham, NC 27706
Principal Investigator:	Franklin, Cocks & Phillip Jones — **Telephone:** (919) 684-2832
Contract Period of Performance:	**From:** 7/1/78 **To:** 4/1/81
Project/Area/Task:	Advanced Silicon/Amorphous Materials

Contract Funding:	FY78 $265,000	FY79 $275,000	FY80 $192,253	FY81 $69,897
Funding Source:	DOE	DOE	SERI	SERI

This program has two main tasks: the investigation of ion-plating as a novel means of producing a-Si:H thin films and the evaluation of these films as a solar cell material and the evaluation of glow discharge produced a-B:H thin films as a solar cell material. On the ion plating task, the following work was done: (1) evaluation of both gas phase and coevaporation doping; (2) measurement of the thermoelastic properties of a-Si:H films produced by glow discharge decomposition; (3) an in-depth study of residual stresses in a-Si:H thin films as a function of substrate temperature and substrate material; (4) examination of the position annihilation Doppler broadening spectra of crystalline Si, a-Si, and a-Si:H; (5) construction of an apparatus to measure the photomagnetoelectric effect, and (6) measurement of the photoconductivity of ion-plated a-Si:H thin films. In preparation for Schottky barrier cell formation, a study has been carried out of the transmittance of Pt-Pd thin films as a function of both wavelength and deposition conditions. Glow discharge-produced a-B:H thin film characterization has included: (1) detailed studies of optical properties as a function of deposition conditions; (2) dark conductivity measurements on both intrinsic and doped a-B:H measurements on a-B:H thin films; (3) evaluation of a-B:H:F thin films; (4) electron spin resonance measurements on a-B:H and a-B:H:F thin films; and (5) photoconductivity measurements.

Title:	Development of Photoelectrochemical Cells Based on Compound Semiconductors and Non-Aqueous Electrolytes	**Contract Number:**	8002-7
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	EIC Corporation 55 Chapel St. Newton, MA 02158		
Principal Investigator:	R. David Rauh	**Telephone:**	(617) 965-2710
Contract Period of Performance:	**From:** 5/1/79 **To:** 3/31/81		
Project/Area/Task:	Polycrystalline Thin Films/Photoelectrochemistry		
Contract Funding:	FY79 $198,275 FY80 $160,909 FY81 $143,374 FY $		
Funding Source:	SERI SERI SERI		

The objective of this project is to produce a family of exceedingly stable and efficient photoelectrochemical solar cells based on compound semiconductors and nonaqueous solvents.

During the third year of this program, research efforts are focused on GaAs and CdSe. The mixed compound semiconductor $CdSe_xTe_{1-x}$ will also be examined. For these photoelectrodes, the factors controlling stability, photovoltage, and photocurrent in aqueous and nonaqueous solvents will be identified. The photoelectrodes will be characterized as single crystals and polycrystalline films.

EIC has investigated a number of nonaqueous solvent-redox couple systems during the first and second year of this work and has decided to focus now on four redox couple systems in acetonitrite for GaAs and cadmium chalcogenide semiconductor photoanodes. Several new device configurations for electrochemical photovoltaic cells have been conceived and are in the process of being executed for promising systems. Experiments are proceeding on very large area photoelectrode systems suitable for electrodeposited thin film materials. A chemical bath deposition for n-CdSe thin films has been demonstrated and efficiencies of up to 5% have been obtained in aqueous electrolytes.

Title: Use of Inorganic Materials for Phosphorescent Concentrating Solar Collectors | **Contract Number:** 8041-13
Directing Organization: Solar Energy Research Institute
Project Engineer: Allen Hermann | **Telephone:** (303) 231-1311
Contractor: EIC Corporation
55 Chapel St.
Newton, MA 02158
Principal Investigator: Peter O'D. Offenhartz | **Telephone:** (617) 965-2710
Contract Period of Performance: **From:** 9/15/79 **To:** 9/30/81
Project/Area/Task: Innovative Concepts
Contract Funding: FY79 $78,581 FY80 $62,468 FY81 $-0- FY $
Funding Source: SERI SERI

The objective of this program is to prepare and characterize inorganic phosphorescent compounds suitable for use in luminescent solar concentrating collectors. Such materials should have extremely low reabsorption coefficients for luminescently emitted light, which should allow the development of large-area, single pane collectors with high concentration ratios.

Four tasks have been identified:

a. Compound selection, based on both theoretical (ligand field theory) and literature data.

b. Compound synthesis.

c. Compound compatibility with various matrix materials.

d. Spectroscopic characterization, including absorption and emission spectra and phosphorescent quantum yield. The results of spectroscopic characterization will be used in further compound selection and characterization.

An extensive literature review of octohedrally coordinated d^3 compounds has been completed. Seven compounds deemed promising have been synthesized. An apparatus for measurement of phosphorescent lifetimes and quantum yields has been constructed, and absorption spectra taken on all of the synthesized compounds. Emission spectra have been taken for one compound, and the remaining spectroscopic characterization is underway. Current efforts are aimed at optimizing the quantum yields of new and previously tested dye compounds.

Title:	Preparation and Characterization of Amorphous $ZnAs_2$ for Use in Solar Cells	**Contract Number:**	9243-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	E. Sabisky	**Telephone:**	(303) 231-1483
Contractor:	EIC Corporation 55 Chapel St. Newton, MA 02158		
Principal Investigator:	R. David Rauh	**Telephone:**	(617) 965-2710
Contract Period of Performance:	**From:** 2/1/79 **To:** 1/14/81		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 \$86,400 FY80 \$43,942 FY \$ FY \$		
Funding Source:	DOE SERI		

The objective of this project is to evaluate the potential of the $A^{II}B^{IV}C^{V}_2$ tetrahedral glasses as solar cell materials.

The research is directed towards four principal tasks to meet this objective:

1. Synthesis and characterization of bulk quantities of $A^{II}B^{IV}C^{V}_2$ compounds.
2. Production of amorphous thin films of these materials.
3. Evaluation of optical and electrical properties of the amorphous materials.
4. Construction and testing of solar cells.

The series of $ZnMAs_2$ and $CdMas_2$ where M = Si, Ge, Sn was made by fusion of the elements. Preparation of the corresponding phosphides was not successful. Thermal evaporation of the ternary compounds to produce thin films resulted in film stoichiometry deficient in the Group IV element. Thin films of amorphous $ZnAs_2$, however, have been prepared with good stoichiometries. The structural, electrical and optical properties of the a-$ZnAs_2$ films are being characterized.

Title:	Low Angle Silicon Sheet (LASS) Process	**Contract Number:**	1303-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Energy Materials Corporation Ayer Rd., P.O. Box 353 Harvard, MA 01451		
Principal Investigator:	D. N. Jewett	**Telephone:**	(617) 456-8707
Contract Period of Performance:	**From:** 9/15/81 **To:** 9/14/82		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY81 \$402,059 FY \$ FY \$ FY \$		
Funding Source:	SERI		

The objective of this program is to perform research on a high productivity ribbon/sheet growth technique which will produce silicon ribbon/sheet suitable for fabricating greater than 10% AM1 efficiency solar cells. The Low Angle Silicon Sheet (LASS) growth technique, an extension of horizontal ribbon growth technique, has the low-cost potential of producing silicon ribbon/sheet with volume productivity similar to that of Czochralski crystal growth.

The approach consists of: (1) LASS process optimization; (2) LASS process scale-up; and (3) solar cell fabrication.

Substantial progress in meeting the objectives has been demonstrated; high speed ribbon growth of 85 cm/min has been achieved. Ribbon growth has attained the following simultaneous parameters: 33 meter length x 5 cm width x 0.65 mm thick, with grains of some mm width in a one hour single seeded growth run (average growth speed of approximately 55 cm/min). Cells have been fabricated from LASS sheet which have demonstrated 10.95% efficiency, as measured by SERI.

Title:	Low Angle Silicon Sheet (LASS) Process	**Contract Number:**	8041-3
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joe Milstein	**Telephone:**	(303) 231-7299
Contractor:	Energy Materials Corporation Ayer Rd., P.O. Box 353 Harvard, MA 01451		
Principal Investigator:	D. N. Jewett	**Telephone:**	(617) 456-8707
Contract Period of Performance:	**From:** 9/15/79 **To:** 6/30/81		
Project/Area/Task:	Polycrystalline Silicon		
Contract Funding:	FY79 $99,700	FY80 $91,500	FY81 $111,842 FY $
Funding Source:	SERI	SERI	SERI

This program addresses research on the low angle silicon sheet (LASS) process to produce silicon ribbons in a high-throughput continuous mode. The objectives of this program are: (1) to optimize the continuous LASS process in growing 10 cm wide, 0.2 mm thick silicon ribbons; (2) to investigate the factors influencing the simultaneous growth of three ribbons (desired width is 10 cm and thickness less than 0.2 mm); (3) to investigate the effects of growth rate, width and thickness on solar cell performance; (4) to assess the cost potential of the LASS process; and (5) to demonstrate the fabrication of large area (greater than 20 cm^2) solar cells with AM1 efficiency of 11% or greater.

Recent progress has included the growth of approximately 33 meters of 5 cm wide ribbon in one hour of continuous growth, the fabrication of 11-12% efficient cells, and control of the dendritic structure of the grown ribbon by improved thermal control.

Title:	Investigation of Materials for Liquid Supported Horizontal Growth of Silicon	**Contract Number:**	9288-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joe Milstein	**Telephone:**	(303) 231-7299
Contractor:	Energy Materials Corporation Ayer Rd., Box 353 Harvard, MA 04151		
Principal Investigator:	D. N. Jewett	**Telephone:**	(617) 456-8707
Contract Period of Performance:	**From:** 8/1/80 **To:** 11/28/80		
Project/Area/Task:	Polycrystalline Silicon Research		
Contract Funding:	FY80 $24,640	FY $	FY $ FY $
Funding Source:	SERI		

The objective of this program is to explore a variation of horizontal silicon ribbon growth which uses a refractory liquid to support the silicon as it is being solidified. Such liquid should not react with the silicon liquid or solid. The advantage of this approach is that the thickness of the ribbon is controlled by the balance of liquid silicon feed and the rate of ribbon withdrawal; the thickness is controlled independently from the pull rate, solidification rate and geometry, or thermal gradients. In addition, the growth process is easy to initiate and the shape of the solidification gradient is continuously controlled without stopping the ribbon growth.

The main effort of this program is the selection of the appropriate supporting liquid. Several fluoride salts have been shown to hold promise. A crystal growth set up has been designed and constructed to test the horizontal ribbon growth. Some of the likely liquid salt candidates are barium fluoride, ytterbium fluoride, and holmium fluoride.

Title:	Spray Solar Cell Research	**Contract Number:**	8104-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Exxon Research and Engineering Company P.O. Box 8 Linden, NJ 07036		
Principal Investigator:	H. Paul Maruska	**Telephone:**	(201) 474-2054
Contract Period of Performance:	**From:** 9/24/79 **To:** 2/28/81		
Project/Area/Task:	Compound Semiconductors/Cadmium Sulfide		
Contract Funding:	FY79 $191,050 FY80 $88,491 FY81 $-0- FY $		
Funding Source:	SERI SERI		

The objective of this project is the development of a spray fabrication process for thin film Cu_2S/CdS solar cells with an engineering efficiency goal of 8% AM1. The methods for fabricating high efficiency CdS/Cu_1S solar cells will utilize a recently developed chemical spray deposition-ion exchange process. The technique involves using the spray deposition method for depositing starting oxide films, followed by an ion-exchange process for converting the oxides to sulfides.

The program will be involved both with characterizing the optical, electrical, and structural properties of the deposited films and with evaluating the performances of completed devices. The studies will include several device configurations, including both frontwall and backwall cells.

To date the CdO spray and CdS conversion processes have been established. The CdS films have been characterized in terms of optical transmission, electrical resistivity, and photoluminescence measurements. Cu_2S/CdS cells have been formed and characterized.

Title:	Thin Film Polycrystalline Silicon Solar Cells		**Contract Number:** 9077-1	
Directing Organization:	Solar Energy Research Institute			
Project Engineer:	R. W. Hardy		**Telephone:** (303) 231-1482	
Contractor:	Exxon Research and Engineering Company P.O. Box 45 Linden, NJ 07036			
Principal Investigator:	A. K. Ghosh		**Telephone:** (201) 474-3465	
Contract Period of Performance:	**From:** 1/1/79 **To:** 5/15/81			
Project/Area/Task:	High Efficiency/Polycrystalline Silicon			
Contract Funding:	FY76 $245,837	FY79 $272,000	FY80 $250,000	FY81 $-0-
Funding Source:	ERDA	DOE	SERI	

The primary objectives of the contract are: (1) to improve the spray deposition processes to further define the maximum capabilities of the SnO_2/n-Si and ITO/n-Si heterojunction solar cells; (2) to assess the stability of such cell structures; (3) to understand the effects of grain boundaries on the electrical and photovoltaic properties of polycrystalline silicon; and (4) to determine the feasibility of a large-scale fabrication process.

In order to fulfill the above stated objectives, SnO_2/n-Si and ITO/n-Si cells are fabricated on single and polycrystalline materials by utilizing the spray deposition technique. The effects of grain size on cell efficiency are studied by fabricating hetero- and homojunction solar cells on different types and grain-size polycrystalline silicon materials. To assess the stability of the various cell structures, detailed degradation tests are carried out. Various measurement techniques have also been developed to analyze the device performance and fundamental mechanisms that could limit cell efficiency.

Power conversion efficiencies (total area) of 13.7% and 11.2% have been achieved on single and polycrystalline silicon, respectively, utilizing the spray deposition process for fabricating heterojunction cells. Diffused homojunction (p on n) polysilicon cells having 10.3% efficiency were also made. Long term stability tests of encapsulated SnO_2/n-Si are being carried out in an outdoor test facility in sunlight. These cells become stable after a small initial drop in the open circuit photovoltage. The effects of grain size on the Hall measurements in polycrystalline silicon have been analyzed and interpreted on the basis of a model that assumes the measured effective Hall voltage is composed of components originating from the bulk and from the space-charge regions. The predictions of such a model are consistent with the experimental results of mm-size Wacker and μm-size neutron-transmutation-doped (NTD) polysilicon materials.

Title:	Sputtered Amorphous Silicon Solar Cells — **Contract Number:** 9219-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	T. McMahon — **Telephone:** (303) 231-7039
Contractor:	Exxon Research and Engineering Company P.O. Box 8 Linden, NJ 07036
Principal Investigator:	Ted Moustakas — **Telephone:** (201) 474-2051
Contract Period of Performance:	**From:** 7/22/80 **To:** 7/21/81
Project/Area/Task:	Advanced Silicon/Amorphous Materials
Contract Funding:	FY80 $280,695 FY81 $389,701 FY $ FY $
Funding Source:	SERI

Progress over the past two years in the preparation and characterization of sputtered hydrogenated amorphous silicon has led to solar cell structures with efficiencies approaching those fabricated by decomposition of silane. Based on this rapid progress, it is clear that sputtering should be considered as an equal partner to glow discharge deposition in terms of process control, and it is anticipated that the development of a prototype solar cell at the laboratory level could be transferred to a mass production scheme much more rapidly than for a similar glow discharge development.

Exxon's a-SiH_x films deposited by RF sputtering have resulted in a solar cell structure with 0.1 cm^2 area having an efficiency of 4%. This would be the first step in a development program leading to a 10% device. Exxon is now approaching the problem with work on an improved p-layer.

Title:	Feasibility Study of a Six-Point Probe Method — **Contract Number:** 9176-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Larry Kazmerski — **Telephone:** (303) 231-1115
Contractor:	Four Dimensions, Inc. P.O. Box 3365 San Mateo, CA 94403
Principal Investigator:	J. T. C. Chen — **Telephone:** (415) 574-0266
Contract Period of Performance:	**From:** 5/30/80 **To:** 5/29/81
Project/Area/Task:	Technical Support/Measurement and Evaluation
Contract Funding:	FY80 $55,867 FY81 $-0- FY $ FY $
Funding Source:	SERI

The objective of this effort is to optimize mechanical and electrical design of a four point probe system in such a way that advanced thin film semiconductor films can be characterized for sheet resistivity. This effort when complete will represent an improvement in the four point probe instrumentation state of the art.

The major problem associated with current 4-point probe systems is the probe loading force. ASTM Standard F-374 allows for a probe force of 30 to 80 gf and an induced potential probe voltage of 10 to 20 mV to characterize single crystal films of 0.2 μm minimum thickness. The loading force is considered excessive for advanced photovoltaic thin films. Reduction of the loading force introduces new problems such as:

- higher contact resistance
- increased current source requirement
- local probe heating and induced space charge effects.

Another problem associated with film resistivity measurements is possible leakage current to the supporting substrate. The leakage current introduces errors in the absolute resistance value and with present probe systems this leakage current cannot be detected or measured.

Instrument research to date has shown that sheet resistivities in the 10^{12} ohm/□ range are possible.

Title: The Polka Dot Solar Cell
Contract Number: 9010-2
Directing Organization: Solar Energy Research Institute
Project Engineer: Lee A. Cole
Telephone: (303) 231-1841
Contractor: General Electric Company
Corporate Research and Development
P.O. Box 8
Schenectady, NY 12301
Principal Investigator: R. N. Hall
Telephone: (518) 385-8103
Contract Period of Performance: **From:** 4/1/80 **To:** 3/31/81
Project/Area/Task: Compound Semiconductor/High Efficiency Concentrators
Contract Funding: FY80 $99,369 FY81 $-0- FY $ FY $
Funding Source: SERI

A new silicon solar cell now under development is expected to achieve high efficiency with low-cost manufacturing. The cell features an array of interconnection paths to carry photocurrent through the cell to metal electrodes on the rear, thus eliminating the collection grid with its attendant losses. This cell is expected to achieve efficiencies approaching the theoretical limit of 22% for silicon with good lifetime under one sun terrestrial illumination; and higher values of concentrated sunlight.

A model was developed for thick epitaxial layer front junction with moderate doping levels. Studies indicate that the optimum thickness would be ~10 μm with a doping level 3×10^{17} cm^{-3} and passivated with an oxide to a surface recombination velocity of $\leq 10^{3}$ cm/sec. Open circuit voltages of 680 mV at 1 sun (AM2) are predicted.

A modified Polka Dot Cell process sequence for contact structures was designed, reducing the metallization contact area. Cells were assembled using this process but no test results have been obtained.

Title:	Regenerative Mode Photoelectrochemical Cells in Aprotic Molten Salt Electrolytes	**Contract Number:**	8041-17
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	Gould Incorporated 40 Gould Center Rolling Meadows, IL 60008		
Principal Investigator:	Jeffrey Phillips	**Telephone:**	(312) 640-4420
Contract Period of Performance:	**From:** 9/15/79 **To:** 6/30/81		
Project/Area/Task:	Polycrystalline Thin Film/Photoelectrochemistry		
Contract Funding:	FY79 $99,980 FY80 $-0-	FY81 $84,927	FY $
Funding Source:	SERI	SERI	

The objective of this program is to investigate the advantages that are expected to arise from the use of aprotic room temperature molten salts (RTMS) as electrolytes for photoelectrochemical cells operating in the regenerative mode.

The approach consists of the following tasks:

- Molten salts such as mixtures of aluminum chloride and alkylpyridinium chloride or bromide, will be prepared and purified. The semiconductors for photoanode will be procured and prepared.
- Investigate the electrochemical behavior of the semiconductor materials in molten salt electrolytes by cyclic voltammetry. Characterize the photoelectrochemical behavior of the semiconductor-RTMS electrolyte system.
- Investigate the electrochemical behavior of several redox couples in RTMS electrolytes by cyclic voltammetry.
- Evaluate the photoelectrochemical stability of the semiconductor/redox couple/RTMS electrolyte system.
- Fabricate and characterize the most promising semiconductor photoelectrode/RTMS electrolyte system.

The aluminum chloride—t-butylpyridinium molten salt electrolyte system has been prepared and characterized. Several redox couples have been characterized by electrochemical means in this system including several ferrocone/ferricinium substituted couple n-GaAs and n-Si semiconductor photoelectrodes have been characterized in this molten salt using a series of redox couples. Of the cadmium chalcogenide semiconductors, only CdSe was found to be stable enough chemically in this molten salt system to proceed with further experiments. Initial experiments indicate that Si is more stable in molten salt electrolytes than in aqueous solutions.

Title:	Electrochemical Photovoltaic Cell II-VI Compound Thin Film Electrodes		**Contract Number:** 8002-8	
Directing Organization:	Solar Energy Research Institute			
Project Engineer:	William Wallace		**Telephone:** (303) 231-1380	
Contractor:	Grumman Aerospace Corp. South Oyster Bay Rd. Bethpage, NY 11714			
Principal Investigator:	Michael A. Russak		**Telephone:** (516) 575-3286	
Contract Period of Performance:	**From:** 6/5/79 **To:** 4/4/82			
Project/Area/Task:	Polycrystalline Thin Film/Photoelectrochemistry			
Contract Funding:	FY79 $211,155	FY80 $221,696	FY81 $187,000	FY $
Funding Source:	SERI	SERI	SERI	

The objective of this program is to develop a stable thin film electrochemical photovoltaic cell with a conversion efficiency (AM1) of 10% or greater.

The approach which will be used in this program includes:

1. CdSe Thin Film Electrodes fabricated by co-evaporation of Cd & Se
   - Ti Substrate
   - SnO_2 coated glass

   $CdSe_xTe_{1-x}$ Thin Film Electrodes by co-evaporation from Cd, Se, and Te
2. Post deposition treatment
3. I-V evaluation
4. Selected further evaluation
   - Optical and electronic
   - Chemical and microstructural
   - PEC
   - Electrolyte variation
5. Correlations among 1 to 4

   Feedback into 1

The current status of the program includes the completion of the basic co-evaporation parametric evaluation and initiation of process variation. Solar energy conversion efficiencies of up to 6.6% have been obtained for CdSe (5 μm) and up to 5.1% for $CdSe_xTe_{1-x}$ by co-evaporation using CdSe and CdTe.

Title:	Measurement Technology for Advanced Solar Cells — **Contract Number:** 8146-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Larry Kazmerski — **Telephone:** (303) 231-1115
Contractor:	Hanford Engineering & Development Laboratory, Richland, WA 99352
Principal Investigator:	S. Price — **Telephone:** (509) 942-4138
Contract Period of Performance:	**From:** 5/1/79 **To:** 4/30/81
Project/Area/Task:	Technical Support/Measurement and Evaluation
Contract Funding:	FY79 $200,000 FY80 $230,000 FY81 $-0- FY $
Funding Source:	SERI SERI

The objectives of this subcontract are to provide physical characterization and chemical analysis of solar cells provided to HEDL by SERI and to review, evaluate, and report on current solar cell measurement methods as well as ellipsometry and infrared electro-thermal methods.

Technical reports have been issued as follows:

A. SERI/TR-98146-1, March 1980, Materials Analysis Methods for Examination of Solar Cells.

B. HEDL TC-1548, May 1980, Current Solar Cell Measurement Methods, Review and Evaluation.

C. HEDL TC-1728, July 1980, Applications of Ellipsometry to Solar Cell Research.

D. HEDL TC-1599, July 1980, Electro-Thermal Infrared Scanning Method for Polycrystalline Solar Cells.

Contract continuation is maintained to provide materials characterization support to SERI. Also, a review of minority carrier lifetime measurements in Advanced Research type devices and electrothermal instrumentation development will be performed.

Title:	Optimization of Transparent Electrode for Solar Cells		**Contract Number:** 9318-1		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	E. Sabisky		**Telephone:** (303) 231-1483		
Contractor:	President & Fellows of Harvard College Office of Research Contracts 1750 Massachusetts Ave. Cambridge, MA 02138				
Principal Investigator:	Roy G. Gordon		**Telephone:** (617) 495-4017		
Contract Period of Performance:	**From:** 9/15/80 **To:** 3/30/83				
Project/Area/Task:	Advanced Silicon/Amorphous Materials				
Contract Funding:	FY80 $27,535	FY81 $92,000	FY $	FY $	
Funding Source:	SERI	SERI			

Solar photovoltaic cell designs usually benefit from a front surface layer which is both transparent and highly conductive to electricity. A practical transparent electrode layer must also be durable, stable to weathering and sunlight, inexpensive, non-toxic, non-polluting, and composed of sufficiently abundant materials to permit widespread use. A film of fluorine-doped tin oxide can meet all these requirements. A new process for depositing fluorine-doped tin oxide films is being optimized by us under SERI contract XS-0-9318-1. The properties of the optimized films are better than any other material now used as a transparent electrode. The goal of the proposed renewal of this contract is to improve the electrical contact between the fluorine doped tin oxide layer and the absorbing layer, such as silicon, which generates the photovoltage in the cell. There is evidence in the literature, and from our preliminary measurements, that significant and deleterious electrical resistance can develop at the interface between tin oxide and silicon. The first goal of our proposed research will be to develop a simple, reliable, and quantitative method to measure this contact resistance. In the second phase of the work, we will use this method to measure the contact resistance between tin oxide and various forms of silicon, including single crystal, polycrystalline, and amorphous silicon. The third and final phase of the proposed work will have as its goal the testing of various means for reducing the interfacial resistance between the transparent electrode and the silicon. Amorphous silicon films will be prepared from CVD of higher silane mixtures. The electronic and optical properties of these films will be studied, and their contact resistance to tin oxide films will be measured and minimized.

Title:	Investigation of a-Si, a-GaAs and Other Amorphous Semiconductors as Materials for Solar Energy Conversion		**Contract Number:** 9358-1	
Directing Organization:	Solar Energy Research Institute			
Project Engineer:	H. Mahan		**Telephone:** (303) 231-1497	
Contractor:	Harvard University Division of Applied Sciences Pierce Hall Cambridge, MA 02138			
Principal Investigator:	W. Paul		**Telephone:** (617) 830-2853	
Contract Period of Performance:	**From:** 8/1/79 **To:** 6/30/82			
Project/Area/Task:	Advanced Silicon/Amorphous Materials			
Contract Funding:	FY79 $239,000	FY80 $236,058	FY81 $180,000	FY $
Funding Source:	SERI	SERI	SERI	

This subcontract addresses fundamental questions regarding the measurement of the density of gap states in amorphous silicon-based materials, and the improvement in amorphous alloy material properties (principally a-SiGe alloys) to an extent that these materials can be considered for incorporation into photovoltaic properties. Regarding the first task, there has been, and continues to be, considerable controversy as to the accuracy of present measurement techniques designed to measure gap state densities. Field effect measurements continue to be plagued with problems of surface or interface state effects and data interpretation, and more recently developed techniques (such as low photon energy optical absorption, capacitance measurements, and deep level transient spectroscopy (DLTS) are not yet advanced enough to allow a definitive interpretation of which produces the most reliable results. Harvard has a long tradition of making such measurements, and has the advantage of making such measurements on identically prepared samples, thus allowing a definitive comparison between the various techniques. Regarding the second issue raised above, the problem to date is that alloying almost invariably degrades solar cell (and material) performance. The Harvard group believes that two compensating mechanisms (escape of hydrogen vs. natural defect healing) are involved when the alloys are annealed, so they are studying alloy performance without hydrogen in an attempt to learn about defects in the unhydrogenated material. Such studies will then be repeated for hydrogenated material, based on the results of the previous studies.

Title:	Investigation of Mechanically Hard, Chemically Inert Antireflection Coatings for Photovoltaic Solar Modules	**Contract Number:**	9010-3
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Honeywell, Inc. (Corp. Tech. Center) 10701 Lyndale Ave., South Bloomington, MN 55420		
Principal Investigator:	Thomas J. Moravec	**Telephone:**	(612) 887-4309
Contract Period of Performance:	**From:** 4/1/80 **To:** 3/31/81		
Project/Area/Task:	High Efficiency Polycrystalline Silicon		
Contract Funding:	FY80 $99,891 FY81 $-0- FY $ FY $		
Funding Source:	SERI		

Carbon thin films that possess "diamond-like" properties have been deposited on silicon by radio frequency plasma and ion beam techniques. However, these films exhibit significant visible light absorption. The objective of this program is to understand the nature of the visible absorption, determine the refractive index of the films and attempt to vary deposition conditions in order to minimize the absorption in the diamond-like carbon thin films.

The approach is to use SIMS and ESCA analysis to study contaminants and entrapped gases in the films. Measurements of the UV, visible, and IR spectra of the films and calculation of the refractive index and absorption from the spectra have been carried out. Hydrocarbon gas composition and deposition plasma conditions will be varied to study the effect of these parameters upon optical properties of the films.

Depositions of "diamond-like" carbon films on silicon have been made with a variety of gases in the plasma (i.e., ethane, butane, etc.). A computer program has been written to determine the optical constants n and k from the measured reflectivity, transmission, and thickness of a film on a transparent substrate. Refractive index (n) values measured for the carbon films on glass slides have averaged 2.24 for wavelengths 4000 Å to 8000 Å. At 6000 Å wavelength high absorption films have k = 0.2. It has been possible to prepare lower absorption films with k = 0.06 by raising the deposition pressure from 10^{-3} torr to 10^{-1} torr. Solar cells coated with such low absorption films exhibit a 40% increase in efficiency (vs. 13% for high absorption films) over an uncoated cell.

Title:	Exploratory Development of Thin-Film Polycrystalline Silicon Photovoltaic Devices	**Contract Number:**	9100-2
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Honeywell Inc. (Corp. Tech. Center) 10701 Lyndale Ave., South Bloomington, MN 55420		
Principal Investigator:	J. David Zook	**Telephone:**	(612) 887-4383
Contract Period of Performance:	**From:** 10/1/80 **To:** 9/30/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		

Contract Funding:	FY80 $712,000	FY81 $426,991	FY $	FY $
Funding Source:	SERI	SERI		

The objective of this exploratory development program is to demonstrate cost-effective solar photovoltaic modules utilizing: (a) thin silicon layers grown epitaxially (EPI) on silicon-on-ceramic (SOC) substrates; or (b) the SOC substrate itself. In the former case, it is anticipated that the added cost of producing the epitaxially grown layer of silicon will be offset by an increase in the solar cell conversion efficiency. It is further anticipated that the increase in the EPI/SOC cell performance will lead to a lower cost per peak watt module than would be attainable with SOC alone.

The program has achieved the following results. Routine uniform silicon coating by inverted meniscus (SCIM) of 1 m long x 10 cm wide slotted ceramic substrates at a rate of 4 cm/min was obtained. Dendrites formed at speeds greater than 2 cm/min., however. The preparation of SOC substrates using metallurgical grade silicon has been achieved. Solar cells of 5 cm^2 area have been fabricated with 10.5% efficiency for dip coated materials, and 8.7% for SCIM-coated ion implanted cells. Epitaxial solar cells on semiconductor grade SOC have been fabricated at Honeywell and RCA with highest efficiencies of 5% to date, without AR coating.

Title:	Research and Development on InP Solar Cells by Plasma Reactive Deposition	**Contract Number:**	9196-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	A. Hermann	**Telephone:**	(303) 231-1311
Contractor:	Hughes Aircraft Company 3011 Malibu Canyon Rd. Malibu, CA 90265		
Principal Investigator:	Ken Zanio	**Telephone:**	(213) 456-6411
Contract Period of Performance:	**From:** 5/24/79 **To:** 6/19/81		
Project/Area/Task:	Emerging Materials		
Contract Funding:	FY79 $119,543 FY80 $233,453	FY81 $-0-	FY $
Funding Source:	DOE SERI		

The objective of this program is to develop the InP/CdS heterojunction system as an all thin film solar cell.

The objectives of the current effort include: (1) deposition of InP on recrystallized (RX)CdS by planar reactive deposition at temperatures low enough to suppress interdiffusion; (2) suppression of the sulfur vapor transport to eliminate its contribution to the InP n-type doping; (3) optical and electrical characterization of the InP layer to determine their device quality; (4) evaluation of the InP/(RX)CdS/ITO/glass structures and correlate the solar cell performance with the InP growth conditions; (5) development of an ITO/p-InP/p+-InP/n+-InP/n recrystallized (RX)CdS frontwall device if the thickness of the n-InP layer cannot be reduced in a manner which is consistent with device quality InP growth; and (6) optimization of the all thin film InP/CdS device structure and an assessment of its potential for achieving a conversion efficiency of 10% or greater.

Some of the program accomplishments are:

1. Defined an optimum substrate temperature range of 300°C-350°C for the deposition of epitaxial p-type InP on RXCdS.
2. Deposited thin films (~1 μm thick) and large grains (~40 μm x 40 μm) of InP on RXCds at 280°C by PRD; presently lower substrate temperature restricted by n-type native defects at 300°C.
3. Prepared all thin film InP/RXCdS devices at 380°C with V_{oc} = 0.55 V but with no light response presumably due to an intermediate n-type layer via S-diffusion from RXCdS.
4. Prepared p-type InP on RXCdS by eliminating S-doping via vapor phase from RXCdS through capping.
5. Increased largest RXCdS grain size to 300 μm.
6. Deposited large grains of CdTe (~30 μm) on RXCdS by physical vapor deposition at 460°C.

Title:	Chemistry and Physics of Silicon-Based Amorphous Semiconductors	**Contract Number:**	9319-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	H. Mahan	**Telephone:**	(303) 231-1497
Contractor:	IBM Thomas J. Watson Research Center Yorktown Heights, NY 10598		
Principal Investigator:	M. Brodsky	**Telephone:**	(914) 945-1338 FTS 8-656-9220
Contract Period of Performance:	**From:** 9/30/80 **To:** 9/29/82		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY80 $168,143 FY81 $197,674 FY $ FY $		
Funding Source:	SERI SERI		

The development of hydrogenated amorphous silicon (a-Si:H) thin films as photovoltaic devices has been extremely impressive in the last few years. In spite of such advances, major problems still exist in the development and production of these materials for reliable devices. In particular, the high efficiency cells (>6% efficiency) almost without exception show an unexplained efficiency decrease upon illumination, and the poor transport in the doped layers remain a stumbling block in obtaining even higher conversion efficiencies than those obtained to date. One method of attacking these problems is by using different deposition methods and novel precursor gases to enable the incorporation of hydrogen and/or dopants into the films in different local environments. IBM has in one year under SERI contract made impressive advances towards obtaining a basic understanding of the physics and chemistry of silicon-based amorphous semiconductors. They have developed a unique deposition process which enables intrinsic film deposition from a single precursor molecule, and with film properties similar to good glow discharge-prepared material. This not only makes the deposition process simpler to understand, model, and possibly control, but also allows the incorporation of hydrogen in amounts previously inaccessible by other deposition techniques. Work is proceeding in fully characterizing the films made by this process, and understanding the device implications of this process. Concerning novel precursor gases, IBM is routinely depositing films from disilane synthesized in house, and has already synthesized other novel precursor gases to tag reaction pathways in the plasma deposition process, and deposit dopants with different local environments.

Title:	Support for PV Consensus Standards Development	**Contract Number:**	9160-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	G. Nuss	**Telephone:**	(303) 231-1287
Contractor:	IEEE 345 E. 47th St. New York, NY 10017		
Principal Investigator:	S. Sheer	**Telephone:**	(212) 644-7966
Contract Period of Performance:	**From:** 6/2/80 **To:** 12/1/81		
Project/Area/Task:	Performance Criteria and Test Methods		
Contract Funding:	FY80 $24,975 FY $	FY $	FY $
Funding Source:	SERI		

This contract is to facilitate implementation of photovoltaic interim performance criteria and test methodologies through consensus standards writing activities. IEEE will establish a Standards Coordinating Committee (SCC) and will provide administrative and logistical support to the SCC and its subcommittees. The activities of the SCC shall be focused on standards development in four major areas for each of which a subcommittee has been established.

Subcommittee 1 (Systems): This subcommittee shall concentrate on the coordination and possible development of standards related definitions of photovoltaic terms, systems power ratings, energy ratings, system element definition, system element qualification, and system element reliability.

Subcommittee 2 (Energy Storage): This subcommittee shall concentrate on the energy storage portion of the PV systems, i.e., standards related to storage systems performance requirements, interface with the array and distribution system, and individual storage element performance requirements.

Subcommittee 3 (Power Conditioning and Control): This subcommittee shall concentrate on the standardization of the power conditioning and control requirements imposed upon the system by its interface with the user (individual or not), the storage system, the array performance, and the solar radiation input conditions. They shall also address the capabilities of conditioning and control option for the development of recommended practice or guidance documents to aid in conditioning and control design development.

Subcommittee 4 (Array): This subcommittee shall concentrate on the standardization of array performance requirements and associated design criteria. These shall cover the electrical performance of the array elements (cells, modules, etc.), its mechanical performance (thermal configuration, optics), and its structural and safety aspects (e.g., toxicity considerations).

Title:	Photoreducing Membranes for Solar Energy Conversion	**Contract Number:**	8041-10
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	Institute of Gas Technology 3424 South State St. IIT Center Chicago, IL 60616		
Principal Investigator:	G. P. Ang	**Telephone:**	(312) 567-5846
Contract Period of Performance:	**From:** 9/25/79 **To:** 7/31/81		
Project/Area/Task:	Polycrystalline Thin Films/Photoelectrochemistry		
Contract Funding:	FY79 $80,236 FY80 $61,196 FY81 $-0- FY $		
Funding Source:	SERI SERI		

The objective of the program is to demonstrate a new concept for photovoltaic conversion using a system composed of a photoreducing membrane and a redox/oxygen electrochemical cell. The emphasis of the program shall be on identifying a suitable match between the photosensitive membrane and the redox couples/electrolyte system.

In order to fulfill the above stated objective, the following tasks will be performed:

Identification of High-Efficiency, Stable Photoreducing Membranes

The objective of this task is to identify a suitable match among the membrane materials, the sensitizer, and the redox couples/electrolyte system. The materials to be evaluated are naturally occurring membrane materials and synthetic membrane materials.

The Integration of Selected Photomembranes

In this task, the complete system composed of the photomembrane cell and the electrochemical cell will be evaluated. Measurements that will be performed in the course of the work will include the following:

- Determine the current voltage characteristics of the redox/oxygen fuel cell as a function of redox species concentration and the partial pressure of oxygen.
- Evaluate the effect of electrolyte flow rate (1 to 10 cm/s).
- Calculate total solar energy conversion efficiency of the system from maximum power output of the redox/air cell relative to the energy of the incident light.
- Determine the long-term stability of the system by detection of soluble corrosion products using polarographic techniques.

In addition the contractor will investigate and identify potential problems dealing with the design, construction, and operation of the total integrated system, as well as specific co~ponents and processes within the system in order to specifically suggest or develop techniques or technology to surmount identified problems.

Title: Electrochemical Photovoltaic Cells **Contract Number:** 9175-1
Directing Organization: Solar Energy Research Institute
Project Engineer: William Wallace **Telephone:** (303) 231-1380
Contractor: Institute of Gas Technology
3424 South State St.
Chicago, IL 60616
Principal Investigator: A. F. Sammells/P. G. Ang **Telephone:** (312) 567-5733
Contract Period of Performance: **From:** 4/15/80 **To:** 3/14/82
Project/Area/Task: Polycrystalline Thin Films/Photoelectrochemistry
Contract Funding: FY80 $151,737 FY81 $151,424 FY $ FY $
Funding Source: SERI SERI

The objectives of this program are to experimentally identify semiconductor photoanode/redox couples which show promise of achieving solar energy efficiencies of 10% with polycrystalline material, together with having the potential utility of being used in a bifunctional electrode assembly. The development of such an electrode configuration would allow the reaction products to be conveniently removed for later discharge at porous flow-through and redox electrodes.

To achieve the above objectives, the following subtasks have been identified: (a) selection of candidate semiconductor/redox couples; (b) electrochemical measurements on selected single-crystal semiconductor/redox couples; and (c) electrochemical measurements on selected polycrystalline semiconductor/redox couples.

Photoelectrochemical characterization of CdSe, $MoSe_2$, and GaAs photoanodes has been performed for application in the redox storage system. The following systems have been evaluated to date: (a) CdSe with S^{2-}/S_n^{2-} as electron donors together with Te_2^{2-}/Te^{2-} as the electron acceptor at the cathode; (b) GaAs with Se_2^{2-}/Se^{2-} as the donor and Te_2^{2-}/Te^{2-} as the acceptor at the cathode; (c) $MoSe_2$ with Br^-/Br_2 as the donor and I^-/I_2 as the acceptor at the cathode; and (d) WSe_2 with Br^-/Br_2 as the donor and I^-/I_2 as the acceptor at the cathode.

The $MoSe_2$ and WSe_2 single crystal layered compounds have shown the most promise to date in terms of efficiency and stability for redox storage cells. Polycrystalline CdSe materials are currently being evaluated for redox storage cells.

Title:	Low Cost Silicon Process Development - Phase IV: Process Improvement			**Contract Number:** 8279-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	Joseph B. Milstein			**Telephone:** (303) 231-7299			
Contractor:	J. C. Schumacher Company 580 Airport Rd. Oceanside, CA 92054						
Principal Investigator:	Edward B. Moore			**Telephone:** (714) 433-1663			
Contract Period of Performance:	**From:** 10/24/77 **To:** 7/31/81						
Project/Area/Task:	High Efficiency/Polycrystalline Silicon						
Contract Funding:	FY77 $139,139		FY78 $69,139		FY79 $210,443		FY80 $155,131
Funding Source:	JPL		JPL		SERI		SERI
Contract Funding:	FY81 $99,154						
Funding Source:	SERI						

The objective of this program is to demonstrate the feasibility of a continuous closed-loop tribromosilane process for the production of solar grade silicon. In order to achieve this objective, the continued operation of the experimental mini-plant is proposed to obtain sufficient operating data and to explore process improvement opportunities. The program also includes basic research study of the tribromosilane decomposition reaction rate in order to gain better understanding of this key process step.

The technical approach to be pursued consists of four tasks, which include: (1) process improvements by operation of the mini-plant under various conditions; (2) determining the reaction rate and order of tribromosilane decomposition; (3) performing heat and material balances to characterize steady state operation, and selecting "best" process conditions; and (4) assessing economic viability of the "best" process conditions.

Over the past year, under the SERI program, efforts have been made to optimize and integrate the individual process steps in a complete, operational mini-plant. The design of the experimental mini-plant has been completed and the construction is underway. In order to fully exploit the potential of this technology, and thus to show the potential of meeting the DOE goals, studies to improve product yield and process economics through mini-plant investigation of improved chemistry and kinetic study of the product reaction to support attempts in improving the reactor design have been carried out. The product is in the process of analysis. The reaction rate observed is not first order, implying a complex set of chemical reactions occurs.

Title:	Commercialization of Thick-Film Solar Cells	**Contract Number:**	8104-2
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Johnson Controls 5757 N. Green Bay Ave. Milwaukee, WI 53201		
Principal Investigator:	Guy D. McDonald	**Telephone:**	(414) 228-2371
Contract Period of Performance:	**From:** 9/15/79 **To:** 4/30/81		
Project/Area/Task:	Compound Semiconductor/Cadmium Sulfide		
Contract Funding:	FY79 $153,975 FY80 $76,968	FY81 $-0-	FY $
Funding Source:	SERI SERI		

The objective of this project is to determine the technical and commercial feasibility of fabricating large area, polycrystalline, heterojunction photovoltaic cells using thick film screening and sintering technology and production scale manufacturing equipment.

The cells will be constructed initially from cadmium sulfide/copper sulfide and later from other possible semiconductor combinations. The minimum cell area will be 25 cm^2. The cell components and the total cells will be characterized as to chemical composition, microstructure, electrical properties, and solar cell performance.

Cadmium sulfide films with a range of resistivities have been made by an established screen printing process using production equipment.

Title:	Development of Thin Film WSe_2 Solar Cells	**Contract Number:**	9050-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Lawrence Livermore Laboratory Livermore, CA 94550		
Principal Investigator:	Dale Miller	**Telephone:**	(415) 422-8782
Contract Period of Performance:	**From:** 1/1/80 **To:** 1/31/82		
Project/Area/Task:	Compound Semiconductor/Emerging Materials		
Contract Funding:	FY80 $168,000 FY81 $145,000	FY $	FY $
Funding Source:	SERI SERI		

The objective of this program is to evaluate thin film formation of tungsten diselenide (WSe_2) for solar cell applications. Two approaches to form thin film WSe_2 are being evaluated: PlasmaVapor Deposition-Reactive Sputtering and Chemical Vapor Deposition (CVD) technique. This involves simultaneous compound synthesis and thin-film growth, and offers significant advantages in simplicity and adaptability to commercialization.

Initial evaluation emphasized x-ray diffractometry to help ascertain when stoichiometric WSe_2 was obtained. Hall effect measurements, scanning electron microscopy, and optical spectrophotometry were used to estimate mobilities, grain sizes, and optical absorption. Direct assessment of lifetimes will later be attempted with coulostatic transient photochemistry techniques recently developed at Lawrence Livermore National Laboratory. Initial runs with XPS have been made to examine W-Se chemical bonding, to complement the XRD spectra, and to seek major impurities.

Initial analysis indicates that stoichiometric WSe_2 thin films have been achieved by both CVD and reactive sputtering.

Title:	Theoretical Determination of Physical Parameters for Solar Cell Materials and Solar Cell Modelling	**Contract Number:**	9071-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Lawrence Livermore Laboratory Livermore, CA 94550		
Principal Investigator:	Jick H. Yee	**Telephone:**	(415) 422-8700
Contract Period of Performance:	**From:** 10/1/79 **To:** 9/30/30		
Project/Area/Task:	Compound Semiconductor/Emerging Materials		
Contract Funding:	FY79 $150,000 FY80 $120,000	FY $	FY $
Funding Source:	DOE SERI		

The objective of this project is to theoretically calculate important optical and transport physical parameters for the new solar cell materials which are important to the characterization of the solar cell, and to model the resultant photovoltaic properties.

The approaches of this project to be taken are:

- To deduce the optical absorption coefficient through the use of the Kramers-Kronig relation if the reflectivity data exist over a wide range of energies.
- A pseudopotential energy band technique will be used to study the band structures of the new materials.
- A normalized concept will be used to study the polycrystalline materials if the average grain size of the material is smaller than the required thickness of the solar cell.
- Effective hole and electron masses, mobility, and minority life-time will be theoretically calculated if these are not available.

Absorption coefficients of Zn_3P_2, Cu_2Se, WSe_2, BAs, $CdSiAs_2$, $CuInSe_2$, and $ZnSiAs_2$ have been theoretically determined. The diffusion length of the minority carriers as a function of the average grain size in these crystals has been calculated. The mobility of the free carriers of these materials has been theoretically investigated. Preliminary modelling of photovoltaic parameters for these materials has also been carried out.

Title: Amorphous Thin Films for Solar Cell Application (Magnetron Sputtered)
Contract Number: 9237-1
Directing Organization: Solar Energy Research Institute
Project Engineer: T. McMahon
Telephone: (303) 231-7039 FTS 327-7039
Contractor: Lockheed Missiles & Space Company
3251 Hanover St.
Palo Alto, CA 94304
Principal Investigator: Art Jonath
Telephone: (415) 493-4411
Contract Period of Performance: From: 3/15/79 To: 7/31/81
Project/Area/Task: Advanced Silicon/Amorphous Materials

Contract Funding:	FY79 $230,000	FY80 $253,000	FY $	FY $
Funding Source:	DOE	SERI		

Magnetron sputtering, a deposition method in which magnetic confinement of a plasma encourages high deposition rates at low working gas partial pressures, is under investigation in this program as a candidate production technology for large-scale manufacture of high-efficiency, thin film amorphous silicon solar photovoltaic cells. Our approach uses two dc magnetron geometries: (1) a low-cost planar magnetron (PM) system for exploratory and detailed examination of deposition parameter space; and (2) a cylindrical magnetron (CM) system, scaleable to production sizes, for deposition of homogeneous films over large areas.

Amorphous silicon films and device structures were sputtered in both PM and CM systems under a wide range of deposition conditions (i.e., T_s, P_{Ar}, P_{H_2}) using both doped and undoped sputter targets. Measured electrical and optical film properties indicate that control over a wide range of conductivity, photoconductivity, conductivity activation energy, and optical and infrared absorption behavior is achievable. Analysis of film oxygen content and distribution profiles indicated that the severe oxygen inclusion by the growing films could be eliminated by a combination of pumping, trapping, and presputter gettering procedures. Films made under these precautionary conditions contain less than 0.1% oxygen.

Multiple depositions to fabricate simple MIS device structures and simultaneously to deposit monitor samples of individual constituent layers have been successful. Such MIS solar cell structures, using semitransparent gold Schottky contacts, have demonstrated photovoltaic behavior. While individual layers, especially the n^+ contact, have yet to be optimized, the best results to date are: $J_{sc} = 4\ mA/cm^2$, $V_{oc} = 0.4\ V$.

Title:	Advanced Photovoltaic Concentrator Cells	**Contract Number:**	8058-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Cole	**Telephone:**	(303) 231-1841
Contractor:	Microwave Associates, Inc. 43 South Ave. Burlington, MA 01803		
Principal Investigator:	R. Frank/J. Goodrich	**Telephone:**	(617) 272-3000
Contract Period of Performance:	**From:** 8/13/79 **To:** 5/12/81		
Project/Area/Task:	High Efficiency Concentrators		
Contract Funding:	FY79 \$210,259	FY80 \$152,832	FY81 \$-0- FY \$
Funding Source:	SERI	SERI	

The program objective is to address the various materials and device areas necessary for continued development of advanced concentrator cells with potential conversion efficiencies in excess of 30%.

A unique etched multiple vertical junction structure in the back surface of the cell will be fabricated using single crystal silicon with alternating p+ and n+ diffused junctions.

Microwave Associates (MA) has developed new cell processing techniques in order to fabricate both n+ and p+ grooved junctions in the back surface. These techniques involve depositing sequentially a layer of thermal SiO_2, then CVD Si_3N_4, and finally CVD SiO_2. Using photolithography and selective etches, MA has successfully etched and doped the n+ grooves, then etched and doped the p+ grooves. In addition, MA has also addressed the reduction of front surface reflection losses and front surface passivation, and the design of the cooling mount to make electrical and thermal coupling to the back-grooved cell. Hydrogen annealing has been identified as one method for reducing the surface recombination velocity of the front surface. A cell mating/interconnect structure has been developed in which metallized Si posts mate to the etched grooves of the cell to make electrical and thermal contact. Further research needs to be carried out to experimentally verify the theoretical model of cell performance, to improve the short-circuit current, open-circuit voltage, and fill factor of the BVJ Si cell.

During the evolution of the mount, the BVJ cell processes were continually changed to accommodate cell and mount mating; a compatible BVJ cell and mount combination was not completed before the end of the contract period. A 25% or greater efficiency at 27°C and 1000 SUNs (AM2) is still deemed feasible.

Title:	PC/TM Support and Interim Safety Guidelines for PV Residential Systems			**Contract Number:**	9009-1		
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	Paul Longrigg			**Telephone:**	(303) 231-1183		
Contractor:	MIT Lincoln Laboratory P.O. Box 73 Lexington MA 02173						
Principal Investigator:	Steve Forman			**Telephone:**	(617) 862-5500		
Contract Period of Performance:	**From:** 7/1/81 **To:** 12/31/81						
Project/Area/Task:	Performance Criteria/Test Methods						
Contract Funding:	FY81 $101,446	FY	$	FY	$	FY	$
Funding Source:	SERI						

The tasks assigned under this contract are designed to employ the technical resources of the MIT/LL PV program in support of the SERI PC/TM task. These tasks are:

1. Develop a set of interim safety guidelines for unfenced lived-in PV residences. First draft will be available late November 1981 for review by a committee comprising representatives from U.L. International Association of Electrical Inspectors and industry. A final draft is scheduled for March/April 1982. This document is designed to fill the need for electrical inspection guidelines until the National Electrical Code adopts PV requirements.
2. Technical support for the 1984 N.E.C. proposals in the form of substantiations has been prepared by Lincoln Lab for additional background for N.E.C. panels on grounding, overcurrent protection, and AC/DC isolation.
3. Continued participation in consensus standard group meetings; i.e., ASTM, IEEE, and N.E.C.

Title:	GaAs Thin Film Solar Cells			**Contract Number:**	9158-1		
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	J. Benner			**Telephone:**	(303) 231-1396		
Contractor:	MIT Lincoln Laboratory Lexington, MA 02173						
Principal Investigator:	John C. C. Fan			**Telephone:**	(617) 862-5500		
Contract Period of Performance:	**From:** 9/30/80 **To:** 2/28/82						
Project/Area/Task:	Thin Film GaAs						
Contract Funding:	FY80 $300,573	FY81	$182,400	FY	$	FY	$
Funding Source:	SERI	SERI					

The objective of this research is to develop very high efficiency thin film GaAs solar cells by obtaining nearly single crystalline GaAs films heteroepitaxially grown on germanium films. Single crystal germanium has been prepared on silicon substrates by evaporation. A second approach requires recrystallization of germanium films deposited on amorphous substrates.

At present, the best devices have been achieved using a shallow homojunction structure (n^+ on p) in GaAs layers grown on Ge/Si substrates. Efficiencies of 11.7% have been demonstrated.

Title:	Amorphous Silicon Thin Film Heterojunction Solar Cells	**Contract Number:**	9056-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	E. Sabisky	**Telephone:**	(303) 231-1483 FTS 327-1483
Contractor:	Mobil Tyco Solar Energy Corporation 16 Hickory Drive Waltham, MA 02154		
Principal Investigator:	Mary Cretella	**Telephone:**	(617) 890-0909
Contract Period of Performance:	**From:** 9/1/78 **To:** 5/1/81		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY78 \$91,204 FY79 \$127,647	FY80 \$233,751	FY81 \$-0-
Funding Source:	DOE DOE	SERI	

The materials science approach of this program has addressed reducing the non-radiative recombination in the a-Si(H) films; reducing the density of gap states and defects in general; and optimizing the energy gap for solar energy conversion.

To accomplish these objectives we have:

- Attempted to create a more fully coordinated matrix structure by substituting Group IVA elements (C, Ge, and Sn) either singly or in combination for part of the silicon.
- Attempted to decrease the remaining defects in hydrogenated material by adding alkali metals (Li, Na, K) to the plasma to interact directly with the defects or to modify and increase the efficiency of the hydrogen defect compensation.
- Determined the variation of optical energy gap and other properties as a function of alloy composition and impurity (doping) levels.

The reference baseline a-Si(H) films show an absorption peak for the Si-H stretching mode at 2000 cm^{-1} and a peak for the rocking mode at 630 cm^{-1}. The films have a density of gap states of 5×10^{15} cm^{-3}, hole diffusion length of 0.3 μm. These films in a non-AR coated, nonoptimized pi-n solar cell configuration give V_{oc} = 0.85 V and an efficiency of 2.0% with E_{og} = 0.8 eV.

Some of the results we have obtained with our a-Si(H) material modification experiments can be briefly summarized as follows:

- The addition of C to the a-Si(H) network shows the complete shift of the Si-H stretching mode frequency to 2100 cm^{-1} from 2000 cm^{-1} and a variation in E_{og} (with C concentration) to values of 2.4 eV.
- The addition of C + Ge changes the character of the Ge incorporation and the distribution of hydrogen in the alloy network. These films show very little photoconductive behavior.
- The addition of Na gives films which are n-type. Although the a-Si(H, Na) films show little change in photoconductive behavior over the a-Si(H) they do not yield good photovoltaic devices in our standard p-i-n configuration.

Title:	Sequential Purification & Crystal Growth for the Production of Low Cost Silicon Substrates	**Contract Number:**	8119-3
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Motorola, Inc. Semiconductor Group 5005 E. McDowell Rd. Phoenix, AZ 85008		
Principal Investigator:	Ming Liaw	**Telephone:**	(602) 244-4616
Contract Period of Performance:	**From:** 9/15/79 **To:** 6/14/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY79 \$210,000 FY80 \$172,798	FY81 \$-0-	FY \$
Funding Source:	SERI SERI		

The objective of this program is to develop techniques for the production of low cost substrates for polycrystalline silicon solar cells. Metallurgical grade silicon is used as starting material. The sequential purification and crystal growth technique is used for the production of silicon. The following summarizes achievements to date by each step of the sequential purification.

1. Chemical Leaching: HCl or aqua regia has been used as a leachant. Impurity removal as a function of leaching time has been studied. Reductions of metallic impurities about one order of magnitude have been obtained.

2. Phase Separation: Techniques using physical separation or vacuum treatment have been developed to separate insoluble impurities from molten silicon. The major elements in the insoluble impurities are Ca and Al.

3. Reactive Gas Treatment: No consistent or reproducible results were obtained when molten silicon was treated by Cl_2, HCl, SiF_4 or H_2O.

4. Slagging: Considerable amount of Al or Sr can be extracted by contacting molten silicon with melts of the mixed oxides CaO-SiO_2 or CaO - MgO-SiO_2.

5. Ingot Pulling: Purification by impurity redistribution using ingot pulling has been found to be the most effective technique. Reduction of impurity concentration by two orders of magnitude or more has been observed.

Silicon wafers produced by this project have ranged from 3 in. to 5 in. in diameter. The impurity concentration is equivalent to that in semiconductor grade silicon with the exceptions of boron, phosphorous, oxygen, and germanium. Experiments have been conducted on solar cell fabrication. 10.1% efficiency was obtained for solar cells fabricated on epitaxial layers with areas in excess of 98 cm^2, as measured by SERI.

Title:	Exploratory Development of Thin-Film Polycrystalline Silicon Photovoltaic Devices	**Contract Number:**	9100-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Motorola, Inc. Semiconductor Group 5005 E. McDowell Rd. Phoenix, AZ 85008		
Principal Investigator:	Kalluri Sarma	**Telephone:**	(602) 244-6413
Contract Period of Performance:	**From:** 9/19/80 **To:** 9/18/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY80 $1,090,000 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this program is to perform research on techniques which will lead to the production of efficient thin film polycrystalline silicon solar cells. The approach used consists of formation of fine grain polycrystalline silicon ribbon by deposition of silicon on a temporary substrate, such as molybdenum, separation of the silicon ribbon from the substrate by the thermal expansion shear separation (TESS) technique, recrystallization of the silicon ribbon using the laser beam or electron beam ribbon-to-ribbon (RTR) method, and solar cell fabrication research. The temporary substrates are intended to be reuseable, and research on this aspect of the technique is also to be carried out.

The program has achieved results which include: the demonstrated reuse of Mo substrates after 6 deposition/TESS cycles with either electropolishing or surface grinding; a semi-continuous system for the simultaneous deposition of 4 microcrystalline silicon ribbons was designed with microcomputer control; both laser beam and electron beam RTR have been demonstrated, and a microcomputer-controlled e-beam recrystallization furnace was made operational in September 1981; large area solar cells have been fabricated, with 11.2% efficiency on 32 cm^2 as measured by SERI. On October 1, 1981, Motorola announced a joint venture with Shell Oil Company to continue the development of this method with the goal of commercially manufacturing solar cell devices using private funds (Wall Street Journal, 10/1/81, p. 8).

Title:	Photovoltaic Mechanisms in Polycrystalline Thin Film Solar Cells	**Contract Number:**	9234-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Motorola, Inc. 5005 East McDowell Rd. Phoenix, AZ 85008		
Principal Investigator:	Bhushan L. Sopori	**Telephone:**	(602) 244-6330
Contract Period of Performance:	**From:** 9/15/79 **To:** 8/29/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY79 $204,243 FY80 $170,257	FY81 $-0-	FY $
Funding Source:	DOE SERI		

Objectives of this program are: (1) development of surface preparation techniques to aid in the unequivocal interpretation of grain boundary (G.B.) data; (2) characterization of G.B.s in terms of chemical, physical, electrical, and optical parameters, and correlation to solar cell performance; (3) identification of the effects of intragrain crystal defects; and (4) determination of effects of solar cell processing on G.B. parameters and bulk defects.

Substrates/cells are analyzed using a variety of electrical/optical measurement techniques to determine local variations in photovoltaic (PV) parameters as well as overall cell characteristics. The PV parameters are then related to defect/G.B. characteristics by determining the types and densities of intragrain defects and other G.B. parameters such as misfit angle, local stresses, and G.B. I-V characteristics. Two types of cells (fabricated on RTR ribbons and Wacker Silso) are used for this study: (1) large area (>2 cm^2) to correlate local variations with overall cell characteristics; and (2) small area (50 mil diameter) to isolate dependences of type and density of defects/G.B.s on cell parameters.

The following techniques have been developed and are being used for this study: (1) two wavelength laser scanning; (2) optical birefringence to determine local stresses; (3) defect characterization by chemical etching and I.R. microscopy; (4) voltage pick-off probe for G.B. characterization; (5) an optical technique for determination of grain orientations; and (6) standard I-V characterization and spectral response analysis of cells.

Title:	High Efficiency Thin-Film GaAs Solar Cells	**Contract Number:**	8171-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	John Benner	**Telephone:**	(303) 231-1396
Contractor:	NASA/JPL 4800 Oak Grove Drive Pasadena, CA 91109		
Principal Investigator:	Y. C. M. Yeh	**Telephone:**	(213) 354-6471
Contract Period of Performance:	**From:** 7/1/79 **To:** 3/31/81		
Project/Area/Task:	Advanced High Efficiency Program		
Contract Funding:	FY79 $258,740 FY80 $69,973	FY $	FY $
Funding Source:	SERI SERI		

The objective of this program is to develop the necessary materials technology for fabrication of thin single crystal GaAs solar cells on silicon substrates coated with a germanium buffer layer. The approach includes development of metalorganic CVD capability and demonstration of high efficiency cells grown on GaAs and germanium substrates; addition of a trimethylaluminum source to the reactor to allow flexibility in selection of solar cell structure; and investigation of techniques for reduction of defect densities in the GaAs films.

The achievements of the program include: preparation of 18% efficient n^+/p shallow homojunction GaAs solar cells by MO-CVD on germanium substrates; addition of the capability for growth of GaAlAs; and demonstration of growth of single crystal germanium layers on silicon substrates without composition grading.

Title: Support for PV Performance Criteria and Test Methods Development **Contract Number:** 1073-1
Directing Organization: Solar Energy Research Institute
Project Engineer: P. Longrigg/G. Nuss **Telephone:** (303) 231-1183/1287
Contractor: NASA/JPL
M/S 510-200
4800 Oak Grove Drive
Pasadena, CA 91103
Principal Investigator: Alan R. Hoffman **Telephone:** (213) 577-9581
Contract Period of Performance: **From:** 5/5/80 **To:** 7/19/82
Project/Area/Task: Performance Criteria/Test Methods
Contract Funding: FY81 $150,000 FY $ FY $ FY $
Funding Source: SERI

Tasks assigned under this contract are designed to employ the technical resources of the JPL/FSA program in support of the SERI PC/TM task. These tasks include:

1. Direct and coordinate SERI's Task Group One (Array Subsystems) to evaluate and develop interim performance criteria (IPC) for the following: array field; array (concentrator, receiver, tracker); panel; module; solar cell.
2. Flat-plate and concentrator solar cells, modules, arrays, and array fields in the development of interim performance criteria.
3. Document existing test methods for array subsystems and develop priorities for required test methods.
4. Participate in national consensus standards activities (ASTM, ANSI, SEMI, IEEE) in support of IPC document development.

Two Task Group 1 subgroups are active: Electrical Performance Subgroup (Chaired by Arizona State University under subcontract from JPL) and the Photovoltaic Environmental Test Method Subgroup. The Photovoltaic Thermal Subgroup completed their activities and was disbanded.

In April 1981, Task Group 1 delivered to SERI twelve criteria and three test methods and several new definitions for inclusion in IPC-2. In addition, several test methods from IPC-1 have been reformatted for IPC-2.

Title:	Solar Cell Measurement Standardization Devices and Procedures	**Contract Number:**	8291-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	P. Longrigg	**Telephone:**	(303) 231-1183
Contractor:	NASA/JPL 4800 Oak Grove Drive M/S 1981B9 Pasadena, CA 91103		
Principal Investigator:	G. Downing	**Telephone:**	(213) 398-4260
Contract Period of Performance:	**From:** 10/1/79 **To:** 1/31/81		
Project/Area/Task:	Performance Criteria/Test Methods		
Contract Funding:	FY80 $252,000 FY $	FY $	FY $
Funding Source:	SERI		

This contract consists of three major tasks:

1. Procedure for determining a spectral response "mismatch index" for photovoltaic devices—this task was directed at developing a quantitative measure to express the degree to which two spectral response curves match. Using this measurement technique a procedure for determining the degree of matching required to keep the error in the measurement of solar cell performance below a specified level.
2. Investigation of solar cell spectral response measurement—this task examined ways in which spectral response is measured in cells and the possible sources and magnitudes of measurement errors. An approach most consistent with practical consideration of the PV community was selected and a draft test method was prepared to measure spectral response of solar cells.
3. Investigation of module spectral response measurements—this task was directed at preparation of a draft test method for measurement of module spectral response.

This work essentially is complete. A draft report has been reviewed and is being revised. The draft test methods from the three tasks have been sent to the ANSI PV subcommittee which assigned them to ASTM.

Title:	Technical Support for the Estimation of Production Prices of Advanced Photovoltaic Modules	**Contract Number:**	9342-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Dr. Byron Jackson	**Telephone:**	(303) 231-7383 FTS 327-7383
Contractor:	NASA-JPL 4800 Oak Grove Drive Pasadena, CA 91103		
Principal Investigator:	Paul Henry	**Telephone:**	(213) 354-9414 FTS 792-9414
Contract Period of Performance:	**From:** 6/3/81 **To:** 8/31/82		
Project/Area/Task:	Technical Support/Advanced Systems Research		
Contract Funding:	FY81 $100,000 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this research study is to estimate the cost of the manufacturing processes which are to be used in the production of advanced low cost solar cells. A list of all processes which are projected for use in the manufacture of low cost solar cells has been developed. This research project involves reducing this list to those processes which are significantly different from each other, characterizing each of these processes and determining their contribution to cost under commercial scale manufacturing conditions.

The first phase of this project will be completed in December 1981. The product will be detailed characterizations of each manufacturing process and cost estimates for a majority of the processes. During the second phase, cost estimates for all manufacturing processes will be completed, the probable range of variation around the cost estimates will be specified, and the implications of each of the manufacturing processes for final cell efficiency will be evaluated.

Title:	Support of Performance Criteria/ Test Standards	**Contract Number:**	1076-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Gary Nuss	**Telephone:**	(303) 231-1287
Contractor:	National Bureau of Standards Washington, D.C.		
Principal Investigator:	Harry Schafft	**Telephone:**	
Contract Period of Performance:	**From:** 7/20/81 **To:** 7/19/82		
Project/Area/Task:	PV Quality Assurances and Standards		
Contract Funding:	FY81 $150,000 FY $	FY $	FY $
Funding Source:	SERI		

1. Identification of Measurement Needs of Industry.

   A. Identify present and anticipated measurement needs and problems regarding the characterization and the processing or assembly control of materials, cells, and modules at the commercial or near-commercial level. The focus will be on industry-oriented problems discussed in anonymity to promote frankness.

   B. Survey and analyze the industry's present and potential use of test structures for cell processing control and determine how and to what extent it will be feasible to apply the test pattern approach to solar cells.

2. Conduct Exploratory Investigation

   A. Conduct an exploratory investigation to ascertain the potential of electromagnetic interference (EMI) caused by radiation from photovoltaic (PV) systems. This will include a determination of the appropriate parameters to be measured, a review of present standards with emphasis on the FCC docket on incidental radiators, three short field trips to measure actual field-strength levels around prototype flat-plate and concentrator PV installations, and a small residential installation having roof-mounted PV arrays.

3. Testing Laboratory Evaluation and Product Certification for PV Reference Cells

   A. Prepare preliminary plans for the development of a laboratory evaluation program for selecting and monitoring a competent independent laboratory which will fabricate and calibrate silicon solar reference cells, and will serve as the source for such cells to the photovoltaic community.

Title: A Program on Solar Cell Measurement Technique Development **Contract Number:** 9313-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Larry Kazmerski **Telephone:** (303) 231-1115
Contractor: National Bureau of Standards
Electron Devices Division
Washington, D.C. 20234
Principal Investigator: M. Bullis **Telephone:**
Contract Period of Performance: **From:** 10/1/78 **To:** 11/30/80
Project/Area/Task: Technical Support/Measurement & Evaluation

Contract Funding:	FY78 $226,900	FY79 $200,540	FY80 $50,000	FY81 $-0-
Funding Source:	DOE	DOE	SERI	

The main objective of the project is to develop improved solar cell measurement techniques.

The approach involves obtaining spatial point-by-point information about cell design, fabrication, and operation using a laser flying-spot scanner and scanning techniques developed at NBS.

The contract performance period has covered approximately three (3) years with initial funding provided by DOE. The present contract is to evaluate the mathematical models developed by the University of Southern California using the scanner. These models provide analytical predictions for the results of scanning forward-biased perfect cells, and of cells with various defects, i.e., cells with point shorts, and cells cracked with and without shunt conductance across the crack.

These results are applicable to cells made from exploratory materials, e.g., polycrystalline cells, as well as single-crystal cells. Reference Structure Array (RSA) wafers have been fabricated from single-crystal silicon. Each wafer incorporates four small (1 cm by 1 cm) solar cells. Three of the cells contain precisely designed "defects," and all four are surrounded by solar cell tests pattern NBS-22 for an independent assessment of the cell and "defect" parameters. The RSA cells will be laser scanned under controlled insolation conditions, and the scanning results will be compared with those predicted from the University of Southern California work with the objective of putting laser scanning of solar cells on a firm analytic base.

Title:	NMR Studies of Hydrogenated Amorphous Silicon	**Contract Number:**	9073-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	F. Jeffrey	**Telephone:**	(303) 231-7036
Contractor:	Naval Research Laboratory 4555 Overlook Ave. Washington, D.C. 20375		
Principal Investigator:	P. C. Taylor	**Telephone:**	(202) 767-3692
Contract Period of Performance:	**From:** 12/15/78 **To:** 3/14/81		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 $122,000	FY80 $130,000	FY81 $55,000 FY $
Funding Source:	DOE	SERI	SERI

Pulsed ^1H NMR experiments (at temperatures between 4.2 and 500K and at frequencies between 10 and 42 MHz) have been used to demonstrate the existence of at least two different hydrogen sites which do not correlate well with infrared vibrational measurements. These NMR results also indicate the presence of disorder modes associated with hydrogen in a-Si:H. As a function of temperature, the NMR spin lattice relaxation rates of ^1H in a-Si:H films exhibit an asymmetric maximum near 40K of ~3 Hz.

Nuclear Magnetic Resonance have established the existence of two separate hydrogen environments in glow discharge deposited a-Si:H. Results for sputtered films have been compared with those obtained for glow discharge samples. The sputtered films have more hydrogen in the highly clustered environments than do the glow discharge films. In addition, films prepared with a low partial pressure of hydrogen in the sputtering gas show no minimum in the spin lattice relaxation time T_1 as a function of temperature, unlike the glow discharge films where a minimum T_1 is observed. This minimum, which is attributed to relaxation via disorder modes, is also seen in a sputtered film prepared under a high partial pressure.

Photoluminescence excitation (PLE) spectra have been obtained at 77K for compacted samples of both glow discharge deposited and reactively sputtered a-sI:H. In all cases the low energy PLE spectra parallel the slope of the higher energy band edge absorption curves obtained from thin films without change in slope down to 1.3 eV. The absence of a slope change or shoulder in the PLE spectra at energies ≤ 1.5 eV indicates that the low energy below gap absorption processes which give rise to the ~1.3 eV shoulder observed in photoconductivity spectra of a-Si:H do not contribute to the excitation of the ~1.3-1.4 eV luminescence band.

Title:	First Principle Theory of Hydrogenated Silicon	**Contract Number:**	9141-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	H. Mahan	**Telephone:**	(303) 231-1497
Contractor:	Naval Research Laboratory X-Ray Optics Branch Washington, D.C. 20375		
Principal Investigator:	D. Papaconstantopoulos	**Telephone:**	(202) 767-3934
Contract Period of Performance:	**From:** 2/21/79 **To:** 12/14/81		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 $93,000 / FY80 $93,000 / FY81 $55,000 / FY $		
Funding Source:	DOE / SERI / SERI		

The coherent potential approximation (CPA) method has been used to obtain the electronic states of a random substitutional alloy of Si, vacancies, and hydrogen. The results of the calculations demonstrate the "cleaning" of the gap states upon hydrogenation and characteristics of both the valence and conduction bands in agreement with experimental observations.

We have also used the self-consistent pseudopotential method to determine the electronic structure of the hydrogen saturated vacancy (HSV) in Si, in which the four dangling bonds at an ideal Si vacancy are terminated by H atoms. The vacancy dangling bond states are found to be removed from the gap, and the H-H interactions do not interfere with the formation of a strong H-Si bond. These results suggest that similar complexes may relieve strain in a-Si upon hydrogenation. This calculation also reveals a potentially observable acceptor state if an HSV-like defect can be created in crystalline Si.

Title:	Lifetime of Minority Charge Carriers in Electronic Materials	**Contract Number:**	1223-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Larry Kazmerski	**Telephone:**	(303) 231-1115
Contractor:	Naval Ocean Systems Center Electronic Materials Science Div. San Diego, CA 92152		
Principal Investigator:	H. Wieder	**Telephone:**	(714) 225-6591
Contract Period of Performance:	**From:** 9/1/79 **To:** 5/4/81		
Project/Area/Task:	Technical Support/Measurement and Evaluation		
Contract Funding:	FY79 $90,000 / FY80 $95,000 / FY81 $1,200 / FY $		
Funding Source:	DOE/SERI / SERI / SERI		

The objective of this research program is to study the fundamental properties of solar cell electronic materials, specifically with those parameters of polycrystalline materials which affect the recombination of optically induced charge carriers and with an explicit evaluation of their charge carrier lifetime.

The approach will be to:

Measure and determine minority carrier lifetimes on polycrystalline semiconducting materials; concentrating initially on the intermetallic semiconducting III-V alloys, to compare these minority carrier lifetimes with the minority carrier lifetimes of corresponding single crystal materials and to relate these lifetimes to the thickness, grain size, crystallographic orientation and distribution of crystallites in these bulk materials and heteroepitaxial layers grown on a variety of substrates.

Correlate the electrical and galvanomagnetic parameters of the polycrystalline materials investigated with optical and electro-optic coefficients, develop appropriate physical model(s) and equivalent circuit(s) and emphasize, in particular, minority carrier lifetime.

Title: Preparation and Characterization of Sputtered Amorphous Silicon
Contract Number: 8142-1
Directing Organization: Solar Energy Research Institute
Project Engineer: T. McMahon
Telephone: (303) 231-7039 FTS 327-7039
Contractor: Naval Weapons Center
China Lake, CA 93555
Principal Investigator: T. Donovan
Telephone: (314) 939-3852
Contract Period of Performance: **From:** 6/1/79 **To:** 7/31/81
Project/Area/Task: Advanced Silicon/Amorphous Materials
Contract Funding: FY79 $141,000 FY80 $135,000 FY $ FY $
Funding Source: SERI SERI

Magnetron deposited films have been shown to have little contamination compared to RF diode deposited layers (H = 0.003, O $\leq$ 0.005 vs. 0.01 to 0.3 for the RF diode deposited layers), the absorption in the 0.5 eV < E <1.5 region is comparable, suggesting this absorption is defect related with both sputtering techniques yielding films with similar defect concentrations. Future work will be directed at attempts to lower the macroscopic defect concentration by varying the substrate temperature and bias, deposition rate, sputter gas composition, and pressure and monitoring changes in structure by transmission electron microscopy measurements. The goal will be to discover why the magnetron film is so reactive. The only way to fabricate Schottky diodes was to grow the Pt or Pd contact on top of the a-Si without a break in vacuum. Finally, the present doping studies will be continued with an emphasis on phosphorous, nitrogen, and oxygen. Best effort produced 1 mA/cm^2 short circuit current and 0.5 V open circuit voltage.

Title: Compensation of Dangling-Bond Defects in a-Si, Ge Alloys
Contract Number: 1071-01
Directing Organization: Solar Energy Research Institute
Project Engineer: T. McMahon
Telephone: (303) 231-7039
Contractor: North Carolina State University
Raleigh, NC 27650
Principal Investigator: G. Lucovsky
Telephone: (919) 737-2512
Contract Period of Performance: **From:** 1/15/81 **To:** 1/14/82
Project/Area/Task:
Contract Funding: FY81 $54,000 FY $ FY $ FY $
Funding Source: SERI

Of the problem areas that still exist in the thin film a-Si area, p-layer development and stability remain at the top of the list. Solutions to developing good p-layers require some type of alloying. With the introduction of another constituent the problem of preferential attachment becomes critical. Also, the solution to the stability problem requires the identification of the defect cluster which is responsible and its removal or neutralization.

This program considers the question of defect neutralization in a-Si, Ge alloys by univalent atoms; hydrogen and the halogens. Application of a local atomic model, based on the chemical properties of the constituent atoms, indicates that hydrogen will preferentially attach to a-Si atom sites in a-Si, Ge alloys. We propose to test this model by preparing alloy films via sputtering and glow discharge decomposition techniques. Hydrogen and fluorine incorporation will be studied by infrared absorption, and defect environments will be probed by ESR, photoconductivity, and optical absorption. Optimization of those optical and electrical parameters of this alloy system which are essential in solar energy conversion applications will be attempted, based on the results of the defect neutralization studies which are proposed.

Title:	Preparation and Characterization of Sputtered Amorphous Silicon	**Contract Number:**	8142-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	T. McMahon	**Telephone:**	(303) 231-7039 FTS 327-7039
Contractor:	Naval Weapons Center China Lake, CA 93555		
Principal Investigator:	T. Donovan	**Telephone:**	(314) 939-3852
Contract Period of Performance:	**From:** 6/1/79 **To:** 7/31/81		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 \$141,000 FY80 \$135,000 FY \$ FY \$		
Funding Source:	SERI SERI		

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Directing Organization:	Solar Energy Research Institute		
Project Engineer:	T. McMahon	**Telephone:**	(303) 231-7039
Contractor:	North Carolina State University Raleigh, NC 27650		
Principal Investigator:	G. Lucovsky	**Telephone:**	(919) 737-2512
Contract Period of Performance:	**From:** 1/15/81 **To:** 1/14/82		
Project/Area/Task:			
Contract Funding:	FY81 \$54,000 FY \$ FY \$ FY \$		
Funding Source:	SERI		

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This program considers the question of defect neutralization in a-Si, Ge alloys by univalent atoms; hydrogen and the halogens. Application of a local atomic model, based on the chemical properties of the constituent atoms, indicates that hydrogen will preferentially attach to a-Si atom sites in a-Si, Ge alloys. We propose to test this model by preparing alloy films via sputtering and glow discharge decomposition techniques. Hydrogen and fluorine incorporation will be studied by infrared absorption, and defect environments will be probed by ESR, photoconductivity, and optical absorption. Optimization of those optical and electrical parameters of this alloy system which are essential in solar energy conversion applications will be attempted, based on the results of the defect neutralization studies which are proposed.

Title:	Studies of Fundamental Growth Problems in Lattice Mismatched Solar Cells		**Contract Number:** 8041-6		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	L. Cole		**Telephone:** (303) 231-1841		
Contractor:	North Carolina State University Raleigh, NC 27607				
Principal Investigator:	John R. Hauser		**Telephone:** (919) 737-2330		
Contract Period of Performance:	**From:** 9/25/79 **To:** 3/14/82				
Project/Area/Task:	High Efficiency Concentrators				
Contract Funding:	FY79 $97,260	FY80 $68,685	FY81 $-0-	FY	$
Funding Source:	SERI	SERI			

The study addresses the fundamental growth problems in lattice mismatched III-V semiconductor layers which have applications to multijunction cascade solar cells. The program objective is to investigate techniques for improving the grown quality of lattice mismatched semiconductor layers.

After a period of constructing and debugging the organometallic chemical vapor deposition system, NCSU has grown undoped GaAs layers with a p-type background doping of $5 \times 10^{15}/cm^3$, n-type Te-doped GaAs layers with carrier concentrations up to $2.4 \times 10^{18}/cm^3$, and AlGaAs layers with Al composition ranging from 2% to 70%. In addition, preliminary layers of GaInAs with up to 20% In have been grown. This baseline work provides the basis for pursuing the effects of substrate orientation and nucleation control which are outlined in the program.

Title:	Photovoltaic Devices Utilizing III-V Compound Semiconductor Superlattice Structures	**Contract Number:**	9010-4
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Cole	**Telephone:**	(303) 231-1841
Contractor:	North Carolina State University Raleigh, NC 27607		
Principal Investigator:	M. A. Littlejohn	**Telephone:**	(919) 737-2309
Contract Period of Performance:	**From:** 3/15/80 **To:** 12/31/81		
Project/Area/Task:	High Efficiency Concentrators		
Contract Funding:	FY80 \$80,750 FY81 \$-0-	FY \$	FY \$
Funding Source:	SERI		

The study addresses the use of superlattices for overcoming the problem of lattice mismatch and bandgap optimization in cascade solar cell structures. In addition, this program will shed new light on the basic growth mechanisms and resulting material and solar cell device properties of compound semiconductors grown by organo-metallic chemical vapor deposition (OM-CVD) and molecular beam epitaxy (MBE). The objective of this program is to study the basic problems pertaining to the utilization of compound semiconductor superlattice structures for solar cell application. The program goal is to determine the potential of superlattice structures for alleviating lattice mismatch and optimizing bandgaps in cascade solar cells in order to ultimately provide low cost, high efficiency solar energy conversion for terrestrial applications.

The approach to achieving the program goal is through performance of the following tasks:

A. Semiconductor superlattice layers of a few micrometers total thickness, consisting of (1) alternating layers of doped and undoped $Ga_{1-x}Al_xAs$ and GaAs, and (2) alternating GaAlAs/GaAs superlattice structure shall be grown by OM-CVD to yield a material with a bandgap of between 1.6 eV and 1.8 eV, depending on layer thickness and composition value chosen. The Ge/GaAs superlattice structure shall be grown by MBE to yield a material with an adjustable bandgap between 1.0 and 1.2 eV.

B. Basic electrical and optical property measurements shall be made on the superlattice layers. These measurements include optical absorption, photoluminescence, resistivity and Hall effect, all versus temperatures as well as Auger analysis to evaluate the nature of the superlattice heterojunction interface. Other physical evaluations (e.g., TEM) shall be carried out if appropriate.

C. Work shall be conducted to study the doping properties of the superlattice structures for the formation of p-n junctions and tunnel junctions. In addition metal semiconductor interfaces to the superlattice layers shall be fabricated for evaluation of Schottky barrier and ohmic contact formation. Devices containing these barriers and/or junctions shall be evaluated for the usual photovoltaic characteristics. A direct comparison with other material systems under study will be made and an assessment of the potential application of superlattice structures to photovoltaic devices will be carried out.

Title:	Infrared Studies of Hydrogenated Amorphous Silicon	**Contract Number:**	9238-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Larry Kazmerski	**Telephone:**	(303) 231-1115
Contractor:	North Carolina State University Raleigh, NC 27650		
Principal Investigator:	G. Lucovsky	**Telephone:**	(919) 737-2512
Contract Period of Performance:	**From:** 5/3/80 **To:** 9/30/81		
Project/Area/Task:	Technical Support/Measurement and Evaluation		
Contract Funding:	FY80 $49,172 FY81 $5,000	FY $	FY $
Funding Source:	SERI SERI		

The purpose of this subcontract is to investigate infrared absorption spectroscopy as a technique for the quantitative analysis of important alloy constituents (hydrogen, oxygen, and fluorine) in amorphous silicon thin films. The major scientific issues are (1) the homogeneity of the films and the extent to which an exponential law for absorption can apply, and (2) the induction effects on both frequencies and oscillator strengths of Si-H vibrations that are produced by a non-statistical distribution of second-neighbor pairs of alloy atoms; e.g., hydrogen and oxygen atoms that are bonded to the same silicon atom.

The research program is to be implemented as follows:

1. Determine the validity of an exponential absorption law for films containing only Si and H, but prepared in different ways, e.g., by glow discharge decomposition of SiH_4 and reactive sputtering.
2. Study the induction effects (on a quantitative basis) associated with second-neighbor pairings, in particular, changes in the oscillator strength of SiH vibrations due to highly electronegative second neighbor atoms, oxygen, and fluorine.
3. Compare the results of infrared transmission spectroscopy with other quantitative analysis techniques such as Nuclear Resonance (NR) and ultra-high vacuum Secondary Ion Mass Spectrometry (SIMS).

Title:	Characterization of Solar Cells Using a Modulated Electron Beam		**Contract Number:** 8313-1		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	Larry Kazmerski		**Telephone:** (303) 231-1115		
Contractor:	Northrop Research and Tech. Center One Research Park Palos Verdes Peninsula, CA 90274				
Principal Investigator:	S. Othmer		**Telephone:** (213) 377-4811		
Contract Period of Performance:	**From:** 9/25/79 **To:** 9/30/81				
Project/Area/Task:	Technical Support/Measurement and Evaluation				
Contract Funding:	FY79 $99,717	FY80 $1,676	FY81 $79,000	FY	$
Funding Source:	SERI	SERI	SERI		

The objective of this program is to establish a novel technique to characterize thin film solar cells in terms of their transport and recombination lifetime properties by means of a modulated beam of a scanning electron microscope, in conjunction with more conventional measurements using optical excitation.

In the proposed work, an existing electron beam test facility will be augmented and improved to implement the experimental methods, and an optical test facility will be modified to permit complementary testing using an optical probe under realistic solar cell operating conditions. Solar cell test devices from a number of candidate technologies for low-cost terrestrial photovoltaic applications will be examined using these new electron beam techniques, and will be characterized in terms of their transport and recombination properties. Suitable analytical techniques will be refined for interpretation of the data and for prediction of optical response. Predictions will be tested by characterization of the photovoltaic response under appropriate conditions of optical and electrical bias.

The technique has been demonstrated at the laboratory level on single crystal solar cells.

A ten month technical progress report shows instrument development work has been essentially completed and some limited solar cell characterization has started.

Title:	Applications of Laser Annealing and Laser-Induced Diffusion to Photovoltaic Conversion		**Contract Number:** 9078-1		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	Simon Tsuo		**Telephone:** (303) 231-7682		
Contractor:	Oak Ridge National Laboratory Oak Ridge, TN 37830				
Principal Investigator:	R. F. Wood		**Telephone:** (615) 574-5781		
Contract Period of Performance:	**From:** 3/1/80 **To:** 2/28/82				
Project/Area/Task:	High Efficiency/Polycrystalline Silicon				
Contract Funding:	FY80 $200,300	FY81 $250,000	FY $	FY $	
Funding Source:	SERI	SERI			

The objectives of this program are to explore the use of laser annealing and laser-induced diffusion techniques in studies of: low-cost junction formation in polycrystalline silicon; grain boundary effects in silicon and determination of the extent to which lasers can be used to induce grain growth and to control the diffusion of impurity and substrate atoms from low-cost substrates into deposited layers.

The approach used in this research is primarily an experimental one but some theoretical support has been given and more is anticipated in the future. Experimental techniques used in the laser annealing and photovoltaic work include many types of electrical property measurements, transmission electron microscopy (TEM), ion implantation, channeling, and backscattering studies, secondary ion mass spectroscopy (SIMS), x-ray diffraction studies, Raman and infrared, deep level transient spectroscopy (DLTS), scanning electron microscopy (SEM) with electron beam-induced current (EBIC) capability. The properties of finished solar cells are evaluated by standard techniques.

Some of the recent accomplishments are:

(1) Lithium diffusion has been shown to be able to reduce the grain boundary barrier heights.

(2) Junction formation by glow discharge implantation followed by laser annealing has been shown to cause less increase in grain boundary recombination than by glow discharge implantation followed by high temperature diffusion (950°/30 min.)

(3) Preliminary studies of the correlation between mismatch angles and electrical properties of silicon grain boundaries did not show any simple relationship.

(4) The silicon CVD system has been modified so that, in the future, in situ laser recrystallization can be performed during film deposition.

Title:	Research Study of Luminescent Solar Concentrators	**Contract Number:**	9357-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Benner	**Telephone:**	(303) 231-1396
Contractor:	Owens-Illinois, Inc. Corporate Technology P.O. Box 1035 Toledo, OH 43666		
Principal Investigator:	P. S. Freidman	**Telephone:**	(419) 247-9832
Contract Period of Performance:	**From:** 2/1/78 **To:** 6/1/82		
Project/Area/Task:	Innovative Concepts		
Contract Funding:	FY78 $239,022	FY79 $208,400	FY80 $228,642	FY81 $305,492
Funding Source:	DOE	DOE	SERI	SERI

The ultimate objective of this research is to produce high efficiency (8-10%) Luminescent Solar Concentrators with concentration ratios sufficient to yield low cost systems. This program is expected to accomplish the following: (1) setting up a methodology for systematically addressing the problem of degradation of organic dyes. This methodology will be aimed at identifying the causes of degradation, the degradation products, and the effect of those degradation products on LSC performance; (2) developing quantitative and qualitative criteria for selection of both organic and inorganic luminescent species for subsequent optimization; and (3) improving the system efficiency and understanding of the operation of prototype Luminescent Solar Concentrators.

3.2% collection efficiency has been achieved with 5-1/2" x 5-1/2" LSC plate composed of two dyes in a polymeric host on a polymer substrate using a silicon solar cell. This efficiency increase (1.9% was previously measured) reflects progress in decreasing the multiple absorption and remission processes. This design also physically separates the two dye species providing better resistance to photodegradation. Luminescence apparatus has been redesigned to allow rapid determination of relative output for a variety of plate sizes. A comprehensive program for evaluation of dye stability has been implemented. Variation of host material has led to increased dye stability. Hybrid studies on both polymeric and glass substrates have been performed. OI is now using the SERI Brite Monte Carlo Computer Code for mid-latitude summer, direct-plus-diffuse solar photon spectrum (previously the NASA-Lewis AM-1.5 direct component power spectrum was used).

Title: Theoretical and Experimental Study of Electrochemical Photovoltaic Cells
Contract Number: 8002-10
Directing Organization: Solar Energy Research Institute
Project Engineer: William Wallace
Telephone: (303) 231-1380 FTS 327-1380
Contractor: The Pennsylvania State University
University Park, PA 16802
Principal Investigator: S. J. Fonash, J. Jordon
Telephone: (814) 865-4831
Contract Period of Performance: **From:** 6/1/79 **To:** 7/31/81
Project/Area/Task: Polycrystalline Thin Film/Photoelectrochemistry
Contract Funding: FY79 $154,633 FY80 $156,010 FY81 $-0- FY $
Funding Source: SERI SERI

The objective of the project is to study electrochemical photovoltaic cells (EPC) both experimentally and theoretically. The materials to be evaluated in EPCs are Si, CdTe, InP, and Fe_2O_3.

The approach which will be used is outlined in the following tasks:

1. Device modelling and materials characterization for optimal choice of EPC structures.
2. Experimental studies to choose optimal redox couples, solvents, supporting electrolytes, and counter-electrode materials.
3. Development of surface preparation techniques to improve stability and efficiency of EPCs.
4. Testing and evaluation of photovoltaic parameters of EPCs.
5. Analysis of electrode stability by identification of impurities in electrodes.

Title: Preparation of a-Si:H Films by Photochemical and Free Radical Initiated Vapor Deposition
Contract Number: 9010-5
Directing Organization: Solar Energy Research Institute
Project Engineer: H. Mahan
Telephone: (303) 231-1497
Contractor: Pennsylvania State University
Chemistry Dept., 152 Davey Lab
University Park, PA 16802
Principal Investigator: Fred Lampe
Telephone: (814) 865-1209
Contract Period of Performance: **From:** 4/1/80 **To:** 7/31/81
Project/Area/Task: Advanced Silicon/Amorphous Materials
Contract Funding: FY80 $95,021 FY81 $-0- FY $ FY $
Funding Source: SERI

Thin films of amorphous Si:H and related systems will be prepared from gaseous silanes using several photochemical and free-radical decomposition techniques. The various techniques to be used include multiphoton infrared laser induced decomposition, vacuum-ultraviolet photodecomposition initiated by the attack of atoms and other free radicals on silane and disilane. The thin films prepared will be studied by a variety of physical and structural characterization tools and compared to corresponding films produced by electric discharge methods. Doping of amorphous Si:H films for physical property and device analysis will also be carried out using the same photochemical and free-radical decomposition methods. The goal of the study is to determine if photochemical and free-radical induced silane decompositions will permit fabrication of amorphous Si:H-based solar cells of increased efficiency.

Title:	Controlled Cadmium Telluride Films for Solar Cell Applications	**Contract Number:**	9131-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Leon Fabick	**Telephone:**	(303) 231-1313
Contractor:	Pennsylvania State University 207 Old Main University Park, PA 16802		
Principal Investigator:	M. B. Das/S. V. Krishnaswamy	**Telephone:**	(814) 455-1666/3704
Contract Period of Performance:	**From:** 4/4/79 **To:** 8/1/81		
Project/Area/Task:	Compound Semiconductor/Emerging Materials		
Contract Funding:	FY79 $73,706 FY80 $77,753 FY81 $-0- FY $		
Funding Source:	DOE SERI		

The program objective is to fabricate and evaluate both n- and p-type CdTe thin films using sputtering techniques, and then to fabricate and analyze thin film homojunction and heterojunction devices.

To meet the above objective, four tasks have been identified:

- Perform theoretical modelling and calculations to identify the limits of CdTe film systems for photovoltaic conversion efficiencies.
- Deposit thin CdTe films and alloys on selected substrates and vary the film deposition conditions to optimize the film properties.
- Characterize the films in their chemical, structural, optical, and electrical parameters.
- Fabricate p-n junction structures and cells and characterize them.

A new separate source, heated substrate, ion sputter system has been installed.

Films produced in a former R.F. sputtering system have been n-type with electron mobilities and concentrations of 8 cm^2/v-Sec and 10^{18} cm^{-3} respectively.

Schottky barrier cells fabricated on these films have n = 1%.

Title:	Photovoltaic and Structural Properties of a-Si:H Thin Films	**Contract Number:**	9227-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	H. Mahan	**Telephone:**	(303) 231-1497
Contractor:	Pennsylvania State University 265 Materials Research Laboratory University Park, PA 16802		
Principal Investigator:	R. Messier	**Telephone:**	(814) 865-3704
Contract Period of Performance:	**From:** 5/15/79 **To:** 5/31/82		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 $93,000 FY80 $96,630 FY81 $83,437 FY $		
Funding Source:	DOE SERI SERI		

As in the previous two years of this subcontract, Penn State will continue to study the preparation-characterization-property relations of a-Si:H films prepared by rf-sputtering. The emphasis in the present subcontract will be to understand the effects of rf-bias sputtering and rf-power variations, both of which contribute to bombardment-induced damage in deposited films, and relate these effects to the optimization of this material for photovoltaic applications. Detailed structural and chemical characterization of all sputtered films is an important part of this research program. In addition to the standard techniques (SIMS, infrared spectroscopy, and transmission electron microscopy), two relatively new techniques will be used—spectroscopic ellipsometry for structural and optical modelling, and atom probe field ion microscopy for investigating some of the important questions concerning boron-doped a-Si:H distribution and local bonding configurations.

Title:	Epitaxial Zn_3P_2 Film Growth by Activated Vacuum Evaporation
Contract Number:	8041-7
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Allen Hermann
Telephone:	(303) 231-1383
Contractor:	Perkin-Elmer Corporation, Norwalk, CT 06586
Principal Investigator:	Donald L. Smith
Telephone:	(203) 762-6916
Contract Period of Performance:	**From:** 9/25/79 **To:** 9/30/80
Project/Area/Task:	Compound Semiconductor/Emerging Materials
Contract Funding:	FY79 $99,036 FY80 $76,766 FY81 $-0- FY $
Funding Source:	SERI SERI

Perkin-Elmer is pursuing research on the vacuum deposition of zinc phosphide (Zn_3P_2), which is a promising emerging material. The technique of activated vacuum evaporation offers certain special capabilities (oxidation-free environment and easy control of stoichiometry) for the study of Zn_3P_2 that are not inherent in other methods. Perkin-Elmer has devised and implemented specialized equipment to support these studies.

Vacuum evaporation of the elements eliminates Zn_3P_2 evaporant synthesis, may entail lower large-scale processing costs, and introduces several process conditions which may permit n-type growth: RF activation of incident vapor, low growth temperature, Zn/P incident flux ratio control, and co-evaporation of dopant elements. Electrical discharge activation of the incident phosphorus vapor is expected to provide both the activation energy needed to achieve a reasonable deposition rate of Zn_3P_2 and the surface energy needed for large grain growth at low temperatures.

To date the UHV Zn_3P_2 film growth system has been assembled and tested. Inability to maintain a stable phosphine plasma has, however, limited the progress in film deposition.

Title:	Polycrystalline Solar Cell/Substrate Growth by Integrated Vacuum Evaporation
Contract Number:	8041-14
Directing Organization:	Solar Energy Research Institute
Project Engineer:	J. Benner
Telephone:	(303) 231-1396
Contractor:	Perkin-Elmer Corporation, Main Avenue—MS 283, Norwalk, CT 06856
Principal Investigator:	Donald L. Smith
Telephone:	(203) 762-6916
Contract Period of Performance:	**From:** 9/23/79 **To:** 6/30/81
Project/Area/Task:	Thin Film Gallium Arsenide
Contract Funding:	FY80 $99,255 FY81 $73,814 FY $ FY $
Funding Source:	SERI SERI

The goal of this project is to demonstrate the potential of integrated semiconductor/metal-substrate vacuum evaporation for producing low-cost, high-efficiency solar cells using GaAs evaporated onto a nearly lattice-matching substrate of evaporated polycrystalline iron.

The technical approach includes three tasks:

a. Baseline GaAs Schottky cell growth on single crystal GaAs,

b. GaAs solar cell growth on single-crystal Fe, and

c. GaAs solar cell growth on polycrystalline Fe.

At present, the fabrication technique for Schottky barrier cells has been established. The performance of the baseline cells is consistent from run to run. Epitaxy of GaAs directly on Fe has not been achieved due to the formation of low melting point eutectics during growth. However, use of a 200 angstrom buffer of strontium fluoride has been shown to prevent eutectic formation and provide an adequate surface to promote heteroepitaxial growth.

Title:	Feasibility Study of a Microwave Heating Application for Solar Cell Fabrication	**Contract Number:**	8041-16
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Photowatt International, Inc. 2414 West 14th Street Tempe, AZ 85281		
Principal Investigator:	Sanjeev Chitre	**Telephone:**	(602) 894-9564
Contract Period of Performance:	**From:** 9/15/79 **To:** 10/3/81		
Project/Area/Task:	High Efficiency Polycrystalline Silicon		
Contract Funding:	FY79 $94,565 FY80 $-0-	FY81 $69,312	FY $
Funding Source:	SERI	SERI	

The objectives of this contract are to investigate the applicability of microwave energy to junction formation, back surface field formation, metallization sintering and combination of these processes.

To achieve these objectives, a microwave system for solar cell fabrication was designed, constructed, and investigated.

Progress has been achieved to the point where simultaneous junction and back surface field formation have been demonstrated for a batch of 50 coin-stacked wafers. Temperatures of 900°C with good uniformity has been attained. The process appears to be cost effective and rapid. Plans have been developed for incorporating this technique into a commercial production sequence.

Title:	Electrohydrodynamic Process for the Production of Large Area Polycrystalline Silicon Sheet	**Contract Number:**	8041-5
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Phrasor Scientific, Inc. 1536 Highland Avenue Duarte, CA 91010		
Principal Investigator:	John F. Mahoney	**Telephone:**	(213) 357-3201
Contract Period of Performance:	**From:** 9/25/79 **To:** 6/1/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY79 $96,931 FY80 $74,755	FY81 $-0-	FY $
Funding Source:	SERI SERI		

The objective of this "Innovative Concept" Program is to demonstrate the technical feasibility of electrohydrodynamics for producing large area polycrystalline silicon sheet for application to photovoltaics.

The electrohydrodynamic (EHD) method developed at Phrasor Scientific, Inc. uses intense electric fields applied to capillary nozzles containing molten silicon material in order to generate charged liquid droplets which are accelerated to a high velocity and subsequently impact on a target substrate. Large area coverage, fast process times, and controlled thickness films are among the potential advantages of this process.

An EHD particle source compatible with molten silicon has been designed and developed. The source has been successfully tested to produce molten silicon droplet beams which have been deposited on graphite, mullite, and single crystalline silicon substrates. Grain size characterization of solidified silicon droplets reveal columnar structures whose lengths are equivalent to the thickness of the quenched droplet. Due to the rapid solidification of silicon droplets on cold substrates or substrates held at 500-700°C, average grain diameters of 1-2 micron are observed with diffusion lengths exceeding 30 microns. Deposits remelted using a strip heater furnace have shown some evidence of increase in grain size.

Title:	Plasma-Assisted CVD of Hydrogenated a-Si at High Deposition Rates Over Large Area Substrates			**Contract Number:** 1273-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	Frank Jeffrey			**Telephone:** (303) 231-7036			
Contractor:	Plasma Physics Corp. P.O. Box 548 Locust Valley, NY 11560						
Principal Investigator:	John Coleman			**Telephone:** (516) 676-4513			
Contract Period of Performance:	**From:** 6/5/81 **To:** 6/15/82						
Project/Area/Task:	Amorphous Materials						
Contract Funding:	FY81 $98,000	FY	$	FY	$	FY	$
Funding Source:	SERI						

This project is designed to determine the capability of Plasma Physics' assymetrical electrode design in depositing large areas of a-Si:H at rapid rates for solar cell use. The principle question to be answered is whether degradation of the material properties will result from increases in size and rate of deposition.

Title:	Plasma-Assisted CVD of Fluorinated, Hydrogenated Amorphous Silicon			**Contract Number:** 8041-2			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	F. Jeffrey			**Telephone:** (303) 231-7036			
Contractor:	Plasma Physics Corp. P.O. Box 548 Locust Valley, NY 11560						
Principal Investigator:	John H. Coleman			**Telephone:** (516) 676-4513			
Contract Period of Performance:	**From:** 9/15/79 **To:** 6/14/81						
Project/Area/Task:	Advanced Silicon/Amorphous Materials						
Contract Funding:	FY79 $79,322	FY80	$82,400	FY81	$-0-	FY	$
Funding Source:	SERI	SERI		SERI			

The objective of this program is to produce low-cost, large-area solar cells by plasma-assisted CVD of fluorinated, hydrogenated amorphous silicon (a-Si:H:F). The successful combination of plasma and CVD processes would retain the significant material cost advantages of plasma-deposited amorphous silicon (a-Si:H) while utilizing the higher optical absorption coefficients and production rates available from CVD.

CVD is known to produce a-Si:H with a higher optical absorption coefficient than plasma-deposition a-Si:H. Unfortunately, the higher temperatures required for CVD of a-Si:H using silane have resulted in excessive dehydrogenation of the a-Si:H and loss in solar cell efficiency. Thus, the present program is directed to techniques for introducing H_2 into the CVD a-Si:H and to utilizing starting gases such as disilane which dissociate and deposit by CVD at lower temperatures than does silane; thereby offering in principle CVD a-Si:H with a higher H/Si ratio and optical absorption coefficient. Also, deposition rates of plasma-deposited disilane are reported to be 10x higher than that of silane.

During the past year, three novel large-area (100 cm^2) a-Si:H solar cells were developed with the following configurations: inverted NIP/SS cells with an improved red response; inverted a-Si:H/a-B:H heterojunction cells with high V_{oc}; and NIP/metal cells with a CVD p-layer grown pyrolytically from silane and diborane. Initial experiments were performed using disilane as the deposition gas for the intrinsic layer in both NIP/SS and PIN/SS structures. Coatings of In_2O_3, using a technique developed by Dr. Ovadyahu, were applied to NIP/SS cells in order to evaluate its potential as a conductive coating in practical amorphous silicon solar cells.

Title:	Thin Film Polycrystalline Silicon Solar Cells	**Contract Number:**	9192-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	Poly Solar Incorporated 2701 National Drive Garland, TX 75041		
Principal Investigator:	T. L. Chu	**Telephone:**	(214) 840-1221
Contract Period of Performance:	**From:** 3/15/79 **To:** 2/13/82		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY79 \$237,204 / FY80 \$273,237 / FY81 \$139,978 / FY \$		
Funding Source:	DOE / SERI / SERI		

The objectives of this contract are to fabricate large area thin film silicon solar cells with AM1 efficiency of 10% or greater with good reproducibility and good yield and to assess the feasibility of implementing this process for manufacturing solar cells at a cost of less than \$500/kWe (in 1980\$).

The technical approach consists of (1) the purification of metallurgical silicon, (2) the preparation of metallurgical silicon substrates, (3) the deposition of a silicon p-n junction structure on metallurgical silicon substrates, and (4) the application of grid contacts and anti-reflection coatings.

The purification of metallurgical silicon by extraction with aqua regia has reduced the concentration of iron to 400-500 ppma and the concentration of aluminum to 25-300 ppma. The substrates (7.5 cm x 28 cm) prepared from aqua regia treated metallurgical silicon consist of large crystallites of many square millimeters in area, and the impurity concentration along the length of the substrates appears to be uniform. Many large area (>30 cm^2) solar cells have been prepared by depositing n^+/p structures of various thicknesses and dopant profiles on the substrates. Heat treatment in inert and oxygen atmospheres has been found to increase the photocurrent. AM1 efficiencies of 8.8% have been obtained. Current work is directed to the optimization of the configuration of the active region of the solar cell and the passivation of grain boundaries.

Title:	Identification of Electronic Structure of Grain Boundaries in Polycrystalline $CuInSe_2$ and InP	**Contract Number:**	1268-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Larry Kazmerski	**Telephone:**	(303) 231-1105
Contractor:	Princeton University Office of Research and Project Administration Princeton, NJ 08544		
Principal Investigator:	Sigurd Wagner	**Telephone:**	FTS 345-4531
Contract Period of Performance:	**From:** 9/1/81 **To:** 1/31/82		
Project/Area/Task:	Solar Cell Research and Development		
Contract Funding:	FY81 \$84,800 / FY \$ / FY \$ / FY \$		
Funding Source:	SERI		

This study focuses on two areas of research. The first is aimed at the identification of the electronic structure of grain boundaries in polycrystalline $CuInSe_2$ and InP. This involves the preparation of bulk polycrystalline $CuInSe_2$ and InP with a series of donor and acceptor concentrations. For thin film studies, samples are obtained in cooperation with other DOE contractors. Typical measurements include the determination of carrier concentration and mobility as a function of temperature with a goal of determining grain boundary potential barriers and bulk grain properties and the evaluation of the Fermi level pinning at grain boundaries. Compositional measurements of grain boundaries will be conducted in cooperation with the SERI Photovoltaic Devices and Measurements Branch. The second portion of this program is concerned with the identification of the effect of interface orientation on diode properties. Primarily (112), (110), and (100) $CuInSe_2$ substrates will be utilized, and the diodes are characterized in the absence of illumination and in the photovoltaic mode.

Title:	Low Cost Sprayed CdTe Solar Cell Research	**Contract Number:**	8104-3
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	A. Hermann	**Telephone:**	(303) 231-1311
Contractor:	Radiation Monitoring Devices, Inc. 44 Hunt Street Watertown, MA 02172		
Principal Investigator:	Gerald Entine	**Telephone:**	(617) 926-1167
Contract Period of Performance:	**From:** 8/15/79 **To:** 2/14/82		
Project/Area/Task:	Emerging Materials		
Contract Funding:	FY79 $164,793	FY80 $91,354	FY81 $244,076 FY $
Funding Source:	SERI	SERI	SERI

The objectives of this program are to develop techniques to deposit films of high electrical quality cadmium telluride (CdTe) by spray pyrolysis and to utilize these techniques to produce thin-film solar cell structures having at least 8% AM1 conversion efficiency.

To meet the above objectives, the following tasks must be addressed:

1. Synthesis of an appropriate water soluble Te compound.
2. Assembly and optimization of the spray pyrolysis apparatus.
3. Deposition of CdS and CdTe films onto suitable substrates and studies of post-deposition treatments.
4. Formation and optimization of the p-n junction and back contact.
5. Materials and solar cell measurements.
6. Studies of cell stability and degradation.

Chemically pure n- and p-type CdTe films have been produced. This is as evaluated by x-ray diffraction and thermoelectric power techniques. 1 cm^2 all sprayed CdS/p-CdTe devices have been fabricated with efficiencies of 3.3% and V_{oc} = 0.60 volts, J_{sc} = 11 mA/cm^2 and FF = 0.5.

Title:	High Efficiency Thin Film CdTe Solar Cells
Contract Number:	9133-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Kim Mitchell
Telephone:	(303) 231-1383
Contractor:	Radiation Monitoring Devices, Inc. 44 Hunt Street Watertown, MA 02172
Principal Investigator:	Gerald Entine
Telephone:	(617) 926-1167
Contract Period of Performance:	**From:** 3/19/79 **To:** 3/31/81
Project/Area/Task:	Compound Semiconductor/Emerging Materials
Contract Funding:	FY79 \$91,000 FY80 \$200,675 FY81 \$-0- FY \$
Funding Source:	DOE SERI

The objective of this program is to develop thin film CdTe solar cells utilizing hot wall vacuum deposition techniques.

To meet the above objective, the following tasks will be addressed:

- Deposit thin-film layers of CdTe onto selected commercial ITO-on-glass substrates.
- Dope the films with In and Cl or I to produce low resistivity n-CdTe, and optimize the CdTe-ITO interface.
- Fabricate p-CdTe using analogous techniques.
- Perform physical, optical, and electrical measurements on the CdTe films.
- Fabricate and characterize CdTe solar cells.

Thin films of n-type CdTe with grain sizes greater than 1 mm have been deposited. These films have low pinhole densities and resistivities in the range of 100-300 ohm-cm. Gold Schottky barrier cells fabricated on this material show efficiencies of around 1.5% with V_{oc} = 0.3 volts, J_{sc} = 7.85 ma/cm^2 (active area) and FF = 0.54.

Title:	Proof of Concept for Processing Research of a-Si Photovoltaic Devices	**Contract Number:**	1169-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	E. Sabisky	**Telephone:**	(303)231-1483
Contractor:	RCA Corporation P.O. Box 432 Princeton, NH 08540		
Principal Investigator:	A. Firester	**Telephone:**	(609)734-2705
Contract Period of Performance:	**From:** 6/1/81 **To:** 5/31/82		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY81 $1,428,677 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this program is to study and conduct research on the elements of an a-Si photovoltaic panel process. The program plan is to evaluate rf and dc deposition techniques; to survey, implement, and quantify methods for device defect detection and control; to study conductive transparent oxides for device fabrication; to research methods for the patterning of monolithic devices; and to test, model, analyze, and optimize amorphous silicon devices.

Emphasis has been placed on researching a-Si deposition on conductive transparent-oxide-clad glass substrates. Recently, we have made PIN cells on these substrates with efficiencies of 6.8% in a dc deposition system without carbon alloying (A = 0.1 cm^2, V_{oc} = 0.8 volts, J_{sc} = 1.26 mA/cm^2, FF = 0.68, Illumination = 99.5 mW/cm^2.

A comprehensive survey of conductive transparent oxides is well underway. Six material sources of indium tin oxide and tin oxide have been studied with regard to stability, uniformity, conductivity, and transmissivity.

Modifications were made to incorporate trap states into a comprehensive, phenomenological device model. The performance characteristics of a-Si solar cells with a fixed density of positively charged traps were simulated. Further modifications to the model software were started to simulate heterojunction devices.

Title:	Amorphous Thin Films for Solar Cell Applications	**Contract Number:**	8254-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	E. Sabisky	**Telephone:**	(303) 231-1483
Contractor:	RCA Corporation P.O. Box 432 Princeton, NJ 08540		
Principal Investigator:	D. E. Carlson	**Telephone:**	(609) 734-3205
Contract Period of Performance:	**From:** 9/11/78 **To:** 10/10/80		
Project/Area/Task:	Advanced Silicon/Amorphous Material		
Contract Funding:	FY79 $625,000	FY80 $286,000	FY $ FY $
Funding Source:	SERI	SERI	

The objective of this program is to develop a low-cost, stable, thin film solar cell based on hydrogenated amorphous silicon (a-Si:H) with a conversion efficiency greater than 10%. The program involves four research tasks: (1) theoretical modelling of transport and defects in a-Si:H; (2) deposition and doping studies; (3) the investigation of new experimental methods for characterizing a-Si:H; (4) the fabrication of solar-cell parameters.

Recently, conversion efficiencies as high as 6.1% have been obtained in p-i-n cells with active areas of 1.1 cm^2. Moreover, p-i-n cells with efficiencies greater than 5.7% have been produced in 3 different glow discharge systems. The solar cell structure is ITO/n-i-p/stainless steel where the ITO (indium-tin-oxide) is deposited by electron-beam evaporation.

The minority carrier diffusion length has been measured for the first time in a-Si:H by means of the photoelectromagnetic effect, and typical values are 0.1-0.2 μm. Similar values have been estimated from the shape of the current-voltage characteristics of p-i-n cell under illumination. Hall mobility measurements in undoped a-Si:H indicate that the mobility is thermally activated with an energy of $\sim$0.13 eV for temperatures above 90°C; thus, the electron transport near room temperature appears to be associated with tunneling in states near the conduction band. Line-of-sight mass spectroscopy has shown an inverse correlation between Si_xH_y groups in the discharge atmosphere and $(SiH_2)n$ groups in the a-Si:H films. Consequently, surface chemistry appears to be playing a dominant role in the deposition of a-Si:H films.

Title: Thin Film Polycrystalline Silicon Solar Cells
Contract Number: 8276-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Joseph B. Milstein
Telephone: (303) 231-7299
Contractor: RCA Laboratories
Princeton, NJ 08540
Principal Investigator: Brian W. Faughnan
Telephone: (609) 734-3170
Contract Period of Performance: **From:** 9/11/78 **To:** 12/12/80
Project/Area/Task: High Efficiency/Polycrystalline Silicon
Contract Funding: FY78 \$174,087 FY79 \$184,885 FY80 \$-0- FY81 \$-0-
Funding Source: DOE SERI

The objectives of this research and development effort are to characterize and correlate the electrical and structural properties of grain boundaries in polycrystalline silicon in order to understand grain boundary mechanisms and their limitations to solar cell performance, and to study the passivation of grain boundaries by phosphorus diffusion, atomic hydrogen, or other promising techniques.

The approach consists of the following tasks: (1) determination of the influence of grain boundaries on the solar cell performance; (2) development of specific techniques to characterize the structural, compositional, electrical, and optical properties of polycrystalline silicon and the correlation to cell performance; (3) development of grain boundary characterization technique to separate grain boundary effects from intrinsic bulk impurity effects; and (4) development of grain boundary passivation techniques.

Techniques for grain boundary effects analysis, i.e., electron channeling, DLTS, SPV, quantum efficiency, and laser scan, have been developed. A new technique to study grain boundaries, laser scan in conjunction with photoconductivity, has been developed; this method identifies barriers at grain boundaries. Recent work includes the correlation of the liquid crystal technique and laser scanning method to identify electrical activity at grain boundaries. Hydrogen passivation of grain boundaries indicates that large grain boundary barriers are significantly reduced.

Title: Amorphous Boron-Silicon-Hydrogen Alloys for Thin Film Heterojunction Solar Cells
Contract Number: 9010-6
Directing Organization: Solar Energy Research Institute
Project Engineer: E. Sabisky
Telephone: (303) 231-1483
Contractor: RCA Corporation
P.O. Box 432
Princeton, NJ 08540
Principal Investigator: A. Moore
Telephone: (609) 734-3244
Contract Period of Performance: **From:** 6/1/80 **To:** 8/31/81
Project/Area/Task: Advanced Silicon/Amorphous Materials
Contract Funding: FY80 \$80,000 FY81 \$-0- FY \$ FY \$
Funding Source: SERI

This program is developing a new type of thin film heterojunction solar cell utilizing an amorphous boron-silicon-hydrogen alloy (a-B:Si:H) in conjunction with the standard hydrogenated amorphous silicon (a-Si:H). The research program involves four tasks: (1) the deposition of a-B:Si:H films under various conditions; (2) the characterization of the electrical and optical properties of these films; (3) the fabrication of a-B:Si:H/a-Si:H heterojunction devices; and (4) the characterization of these devices. Preliminary results indicate that the films can be made reasonably conductive ($10^{-3}\ \Omega^{-1}\ cm^{-1}$) and are p-type. Moreover, the optical absorption coefficient is significantly less than that of boron-doped a-Si:H over the visible light range.

Title:	Exploratory Development of Thin Film Polycrystalline Silicon Photovoltaic Devices	**Contract Number:**	9100-3
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	RCA Laboratories P.O. Box 432 Princeton, NJ 08540		
Principal Investigator:	A. H. Firester	**Telephone:**	(609) 734-2705
Contract Period of Performance:	**From:** 10/1/80 **To:** 11/15/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY80 $1,197,879 FY $	FY $	FY $
Funding Source:	SERI		

The objective of this exploratory development program is to perform research on the fabrication of low cost, efficient solar cells produced on epitaxial layers of silicon deposited on metallurgical silicon substrates. The approach involves the preparation of metallurgical silicon wafers sliced from ingots of silicon cast by the Heat Exchanger Method (HEM) at Crystal Systems, Inc., followed by epitaxial silicon deposition and cell fabrication at RCA Laboratories. Additionally, epitaxial deposition and solar cell fabrication on Honeywell's SOC material are being investigated.

Progress in this work has included: uniform epitaxial growth on wafers ranging from 3 inch diameter rounds to 4 inch squares in the High Throughput Reactor (HTR); production of baseline epitaxial cells of 13.2% efficiency (Subcontractor's measurement); completion of conceptual study of continuous vs. batch processes for large scale epitaxial growth; demonstration of applicability of low cost cell fabrication processes (i.e., screen printed Ag metallization, spray AR coating) to thin epitaxial film cells; and identification of a particulate (primarily S:C) problem with HEM substrates using metallurgical silicon feed material, which affects yield and efficiency of large area epi/HEM cells, and which appears to be mitigated by use of low carbon content feedstock.

Title:	Amorphous Thin Films for Solar Cell Applications	**Contract Number:**	9372-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	E. Sabisky	**Telephone:**	(303) 231-1483
Contractor:	RCA Corporation P.O. Box 432 Princeton, NJ 08540		
Principal Investigator:	D. E. Carlson	**Telephone:**	(609) 734-3205
Contract Period of Performance:	**From:** 10/1/80 **To:** 3/31/82		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY80 $1,241,836 FY81 $-0-	FY $	FY $
Funding Source:	SERI		

The objective of this program is to develop a low-cost, stable, thin-film solar cell based on hydrogenated amorphous silicon (a-Si:H) with a conversion efficiency greater than 10%. The program involves six research tasks: (1) theoretical studies of a-Si:H; (2) deposition and doping studies; (3) development of new experimental methods to characterize a-Si:H; (4) fabrication of solar-cell structures; (5) theoretical and experimental evaluations of solar-cell characteristics; and (6) stability studies.

Recently, a-Si:H solar cells with conversion efficiencies in the range of 6-7% have been fabricated on both glass and steel substrates. We have obtained values of the open-circuit voltage as high as 933 mV and fill factors as high as 0.713.

A new technique based on surface photovoltage has been developed to measure the diffusion length in a-Si:H, and values greater than 0.5 μm have been observed for undoped films grown in four different discharge systems. Hall mobility measurements on lightly doped, p-type films indicate values as high as 0.2 cm^2/V-s, comparable to the electron Hall mobilities in undoped films.

Another new diagnostic technique involves surface photovoltage profiling of solar-cell structures to determine the spatial variation of the built-in potential.

DLTS measurements indicate a strong correlation between the density of metastable defects in undoped a-Si:H and the concentration of impurities such as oxygen and nitrogen.

Title:	Reliability and Data Analysis Techniques for PV Solar Energy Systems	**Contract Number:**	1061-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	G. Nuss	**Telephone:**	(303) 231-1287
Contractor:	Reliability Tech. Assoc. 13947 Arapaho Lockport, IL 60441		
Principal Investigator:	R. T. Anderson	**Telephone:**	(312) 349-9590
Contract Period of Performance:	**From:** 6/1/81 **To:** 4/12/82		
Project/Area/Task:	Performance Criteria & Test Methods		
Contract Funding:	FY81 $66,324 FY $	FY $	FY $
Funding Source:	SERI		

The purpose of this contract is to develop life-cycle reliability and data analysis techniques and methods which are applicable to photovoltaic (PV) solar energy systems. The methods are to be based on accepted statistical and reliability practices but must be extended, modified, or otherwise tailored to the unique characteristics of PV solar energy systems and to the environment in which they must operate.

Reliability and data analysis techniques and methods, once fully developed, will be applied to data available from laboratory and inplant testing and from operational experience to support validation of performance requirements, criteria, and testing methods to assure that they provide the intended control and predictive capability before being adopted as standards and codes.

The proposed methods will provide a focal point for life-cycle system analysis as well as for validating performance requirements, criteria, and test and engineering methods related to reliability and maintainability (R/M).

The general approach to developing suitable methods involves adopting proven analysis methods for application to PV systems. The work consists of five (5) tasks as follows:

Task 1: Review existing analysis methods to identify those methods that can be readily adopted or provide a baseline for formulating appropriate PV system R/M analysis methods.

Task 2: Adopt the methods identified during Task 1 to be readily applicable to PV systems and component analysis.

Task 3: Demonstrate the methods by conducting analysis of data and other information from a selected PV system application.

Task 4: Formalize the methods into complete procedures ready for use.

Task 5: Prepare a plan for updating and refining the analysis methods.

Title:	Research on Thin Film GaAs Solar Cells	**Contract Number:**	9002-4
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Benner	**Telephone:**	(303) 231-1396
Contractor:	Rensselaer Polytechnic Institute ESE Department Troy, NY 12181		
Principal Investigator:	S. K. Ghandhi	**Telephone:**	(518) 270-6333
Contract Period of Performance:	**From:** 3/1/80 **To:** 2/28/82		
Project/Area/Task:	Thin Film Gallium Arsenide		
Contract Funding:	FY80 $263,454 FY81 $261,994 FY $ FY $		
Funding Source:	SERI SERI		

The objective of this contract is to develop the technology necessary to produce GaAs solar cells of 10% conversion efficiency in films of less than 10 microns thickness which have been deposited by metallorganic CVD on low cost substrates.

The approach requires optimization of MO-CVD process parameters for deposition of films with good structural and electrical properties on low cost substrates. Electrochemical, DLTS, SEM, and other diagnostic techniques will be applied to provide definitive structural, compositional, and electrical characterization. Schottky barrier solar cells will be fabricated and tested as a gauge of progress.

The best cells are approximately 7.1% efficient and are of the AR coated, gold-GaAs Schottky barrier structure. A diffusion technique for producing p-n junction cells in polycrystalline GaAs is under development. Extremely abrupt, shallow junctions have been obtained in single crystal test samples.

Title:	Development of High Efficiency Cascade Solar Cells	**Contract Number:**	8136-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Cole	**Telephone:**	(303) 231-1841
Contractor:	Research Triangle Institute P.O. Box 12194 Research Triangle Park, NC 27709		
Principal Investigator:	S. Bedair/J. Hauser	**Telephone:**	(919) 541-5912/(919) 737-2330
Contract Period of Performance:	**From:** 1/24/78 **To:** 11/30/82		
Project/Area/Task:	High Efficiency Concentrators		
Contract Funding:	FY78 \$367,140 · FY79 \$297,000 · FY80 \$-0- · FY81 \$529,623		
Funding Source:	Sandia · SERI · · SERI		

The basic objective of this work is to continue the development of high efficiency (30% or more) cascade solar cells.

Research Triangle Institute (RTI) under a SERI contract has been investigating both theoretically and experimentally the various requirements for achieving high conversion efficiencies in monolithic cascade cells, in which a low bandgap junction and high bandgap junction are fabricated on a single substrate and electrically connected by an intermediate tunnel junction. RTI under a previously Sandia-sponsored program demonstrated open-circuit voltages above 2.3 V in a seven-layer GaAs/AlGaAs two-junction structure, verifying the electrical and optical cascade action of this approach. In the existing SERI program, RTI's work has emphasized the materials development and evaluation of four candidate materials systems, namely GaAlAs/GaAs, AlGaAsSb/GaAsSb, GaAlAs/GaAsSb, and GaInP/GaInAs. In each of these systems, the top junction and tunnel junctions are fabricated in the first material indicated and the bottom junction in the second material. RTI has demonstrated the low bandgap GaAs, GaAsSb, and GaInAs junction. The high bandgap junctions in AlGaAs (up to 1.9 eV) and AlGaAsSb (up to 1.7 eV) have been fabricated by liquid phase epitaxy, and low impedance AlGaAs tunnel junctions (up to 1.9 eV) have been demonstrated. Preliminary work has also begun developing an organometallic-vapor phase epitaxy (OM-VPE) growth system to be devoted to the evaluation of the GaAlAs/GaInAs and GaAlAsSb systems. Concerning the overall device development a combined structure consisting of a GaAs bottom junction and high bandgap AlGaAs tunnel junction has been demonstrated. A major problem that remains is improving the performance of the top cell when grown on top of the highly doped layers of the connecting junction.

Title:	Development of High Efficiency Low Cost $ZnSiAs_2$ Solar Cells	**Contract Number:**	9142-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Research Triangle Institute P.O. Box 12194 Research Triangle Park, NC 27709		
Principal Investigator:	J. E. Andrews, Jr.	**Telephone:**	(919) 629-5930
Contract Period of Performance:	**From:** 4/9/79 **To:** 3/1/82		
Project/Area/Task:	Compound Semiconductors/Emerging Materials		
Contract Funding:	FY79 $128,737 · FY80 $147,327	FY81 $108,952	FY $
Funding Source:	DOE · SERI	SERI	

The objective of this program is to determine the properties and suitability of $ZnSiAs_2$ as a solar cell material. $ZnSiAs_2$ is a structural analog to the III-V semiconductors having similar electrical and optical properties. At the same time, less critical constituents are used than the III-V compounds, and thus offer more economical materials for photovoltaics.

To meet the described objective, the following specific areas are being addressed:

- Develop organometallic-CVD deposition technique to controllably grow $ZnSiAs_2$ on low cost substrates.
- Demonstrate controllable technique to dope $ZnSiAs_2$ both n- and p-type.
- The fabrication of Schottky barrier, heterojunction, and homojunction structures.
- An evaluation of the suitability of $ZnSiAs_2$ for solar cells.

Both n- and p-type films have been produced by deviating the stoichiometry during growth. Electron densities are typically in the 10^{15} to 10^{16} cm^{-3} range with mobilities of about 25 cm^2/v-sec. Hole concentrations are 9×10^{17} cm^{-3} with mobilities less than one.

N-type zinc-silicon arsenide on p-type silicon heterojunction structures have been fabricated. AMl cell parameters of $V_{oc} = 0.4V$, $J_{sc} = 0.64$ ma/cm^2 and FF = 0.31 have been achieved.

A zinc-silicon-arsenide homojunction structure has been fabricated.

Title: Polymer-Semiconductor Junctions for Solar Cell Applications — **Contract Number:** 8041-1
Directing Organization: Solar Energy Research Institute
Project Engineer: John Benner — **Telephone:** (303) 231-1396
Contractor: Rockwell International Science Center
Thousand Oaks, CA 91360
Principal Investigator: M. Cohen — **Telephone:**
Contract Period of Performance: **From:** 9/15/79 **To:** 12/31/80
Project/Area/Task: Innovative Concepts
Contract Funding: FY79 $98,931 FY $ FY $ FY $
Funding Source: SERI

The study addresses the use of polymer-semiconductor junctions in solar cell applications. The material of interest is polymeric sulfur-nitride, $(SN)_x$, and its derivative $(SNBr_{0.4})_x$. The objective of this program is to investigate the use of polymer-semiconductor (P-S) and polymer-insulator-semiconductor (P-I-S) structures for solar cells. The program goal is to determine the potential of P-S and P-I-S structures to ultimately provide low cost, high efficiency solar energy conversion for terrestial applications.

Task 1: Fabrication and Evaluation of P-S and P-I-S Solar Cells

Polymer-semiconductor and polymer-insulator semiconductor solar cells shall be fabricated, consisting of $(SN)_x$ deposited on GaAs and silicon substrates. This shall be done in the glass sublimation systems already in operation at the contractor's facilities. Efforts shall be made to control the thickness of the $(SN)_x$ overlayer. All cells fabricated shall be evaluated to determine their electrical characteristics which include: (1) illuminated I-V to determine circuit current density, open circuit voltage, and conversion efficiency; (2) spectral response measurements to optimize the structures, (3) C-V measurements to determine effective barrier heights; (4) dark I-V measurements to determine effective barrier heights; and (5) dark I-V measurements to determine series and shunt resistance.

Task 2: Fabrication and Evaluation of Bromine Modified Structures

Cells fabricated in Task 1 which have not been set aside for stability investigation (Task 3) shall be modified by exposure to controlled atmospheres of bromine vapor in order to dope the $(SN)_x$ into $(SNBr_{0.4})_x$. All of the cell characterizations described in Task 1 will be repeated for these modified structures. Efforts shall be made to increase short circuit current due to the increased spectrum transmissivity of $(SNBr_{0.4})_x$ and to increase fill factors due to its lower resistivity.

Task 3: Stability Investigations

Some of the more successful cells fabricated in Task 1 and Task 2 shall be studied in and inert atmospheres and recharacterized periodically to determine any degradation of performance with time.

Title:	Advanced Photovoltaic Concentrator Cells	**Contract Number:**	8058-2
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Cole	**Telephone:**	(303) 231-1841
Contractor:	Rockwell International Electronics Research Center P.O. Box 1085 Thousand Oaks, CA 91360		
Principal Investigator:	Stanley Zehr	**Telephone:**	(805) 498-4545, ext. 145
Contract Period of Performance:	**From:** 8/28/79 **To:** 12/29/81		
Project/Area/Task:	High Efficiency Concentrators		
Contract Funding:	FY79 $242,401 · FY81 $340,112	FY $	FY $
Funding Source:	SERI · SERI		

The objective of this project is to demonstrate monolithic, stacked multibandgap solar cells having 30% conversion efficiency at 30°C and 25% conversion efficiency at 150°C under 500-1000 SUN AM2 illumination.

To meet the described objective, the following tasks will be performed:

1. Growth and optimization of single junction AlGaAs cells having bandgaps of 1.6 eV and 1.7 eV and GaAlSb cells having bandgaps of 0.95 eV and 1.1 eV.
2. Development of techniques for joining these optimized single junction cells by means of non-lattice matched ohmic intercell contacts having sufficiently high optical transparency combined with low electrical and thermal resistance to meet the overall performance objective.
3. Characterization of the performance of the individual cells and stacked combinations using appropriate light and dark I-V and photoresponse measurements over the operating temperature range of 30-200°C and for illumination levels of 1-1000 SUNs AM2.

Some of the accomplishments to date are:

1. Successful growth of the AlGaAsSb subcells by LPE. Open-circuit voltages as high as 0.35 V, 0.55 V and 0.66 V were achieved at 1 SUN, ~200 SUNS and ~1000 SUNS respectively.
2. Successful growth of the AlGaAs subcells by MO-CVD.
3. Demonstration of the intercell bonding between GaAs and GaSb using intermediate layers of elemental Al and Sb. By heating sufficiently, complete alloying occurs to form an AlGaAsSb interface region which has good optical transparency for the low bandgap junction and good lattice grading.

Title:	Gallium Arsenide Peeled Film Solar Cells	**Contract Number:**	9002-2
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Benner	**Telephone:**	(303) 231-1396
Contractor:	Rockwell International Electronics Research Center P.O. Box 1085 Thousand Oaks, CA 91360		
Principal Investigator:	David Miller	**Telephone:**	(805) 498-4545
Contract Period of Performance:	**From:** 3/15/80 **To:** 10/14/81		
Project/Area/Task:	Thin Film Gallium Arsenide		
Contract Funding:	FY80 $225,000 FY81 $138,000	FY $	FY $
Funding Source:	SERI SERI		

The goal of this program is to determine the technical merit and cost feasibility of basic process steps involved in the fabrication of GaAs peeled film solar cells. Several approaches to cell growth, bonding the cell, separating the cell from the reusable substrate, and processing methods will be investigated. The solar cell performance goal of this program is to demonstrate a 15% efficient peeled film GaAs cell using a process selected on the basis of potential for production of the peeled film cells at the lowest cost per kilowatt of power produced by the cells.

The technical approach of this program is to grow GaAs solar cells on AlGaAs parting layers having AlAs content from 50% to 100%. The etch rate and preference ratio of various echants will be evaluated as a function of parting layer thickness and aluminum content. Bonding and handling techniques will be developed for processing the thin film GaAs solar cells. The electrical and optical properties of complete solar cells, bonded to low cost substrates, will be characterized. Finally the feasibility of process scale-up and estimated cell costs will be evaluated.

Title:	Electrodeposition of Device Quality Semiconductor Materials	**Contract Number:**	9010-7
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	W. Wallace	**Telephone:**	(303) 231-1380
Contractor:	Rockwell International 1049 Camino Dos Rios P.O. Box 1085 Thousand Oaks, CA 91360		
Principal Investigator:	D. M. Tench	**Telephone:**	(805) 498-4545
Contract Period of Performance:	**From:** 4/1/80 **To:** 7/1/81		
Project/Area/Task:	Polycrystalline Thin Film/Photoelectrochemistry		
Contract Funding:	FY80 $97,316 FY81 $-0-	FY $	FY $
Funding Source:	SERI		

The objective of this work is to prepare device quality electrodeposited thin films of CdTe and GaAs.

In the program considerable attention will be devoted to system choice, electrolyte purity, electrolyte mass transport, potential distribution, temperature effects and perturbation choice. Various deposition systems will be evaluated using steady state and transient electrochemical methods and a.c. impedance techniques. Electrodeposition will be performed on polycrystalline and single crystal substrate. Electrodeposits will be evaluated and characterized by conductivity measurements, scanning electron microscopy, x-ray diffraction and photoelectrochemical measurements.

Title:	Electrochemical Photovoltaic Cells: Stabilization and Optimization of II-VI Semiconductors	**Contract Number:**	9276-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	Rockwell International 1049 Camino Dos Rios Thousand Oaks, CA 91360		
Principal Investigator:	Dennis Tench	**Telephone:**	(805) 498-4545
Contract Period of Performance:	**From:** 4/15/80 **To:** 3/14/82		
Project/Area/Task:	Polycrystalline Thin Films/Photoelectrochemistry		
Contract Funding:	FY80 $219,833	FY81 $169,648	FY $ FY $
Funding Source:	SERI	SERI	

The objective of this program is to develop new electrolyte redox systems and electrode surface modifications which will stabilize the II-VI compounds against photodissolution without seriously degrading their performance in electrochemical solar cells.

The approach which will be used includes applying electrochemistry, synthetic chemistry, and materials characterization in concert to evolve a practical compromise between the interfacial chemistry and the device characteristics. This involves: (a) preparation of new redox systems; (b) development of synthetic procedures for modifying CdX electrode surfaces; (c) preparation of mixed II-VI electrode materials; (d) evaluation of the photoelectrochemical properties of II-VI electrodes, with and without surface modifications, in various redox electrolytes; (e) characterization of the chemical and electrical properties of II-VI electrode materials before and after use as photoanodes; and (f) comparison of electrochemical and Schottky barrier cells based on II-VI materials.

The current status of the program includes the following observation: CdSe/methanol/ferro-ferricyanide has been identified as a promising photoelectrochemical system. Polypyrrole films have been electrodeposited on CdSe and GaAs semiconductor surfaces and have been shown to significantly stabilize these materials in aqueous electrolytes and have been shown to be conducting. The work on semiconductor surface modification using conducting polymer films has been extended to other polymer materials. Polycrystalline CdSe and $CdSe_xTe_{1-x}$ films as photoanodes have been characterized in the methanol/ferro-ferricyanide system.

Title: Purification of Metal/Organic Compounds **Contract Number:** 9430-1
Directing Organization: Solar Energy Research Institute
Project Engineer: L. Cole **Telephone:** (303) 231-1841
Contractor: Rockwell International
1049 Camino Dos Rios
Thousand Oaks, CA 91360
Principal Investigator: J. S. Harris **Telephone:** (805) 498-4545
Contract Period of Performance: **From:** 10/1/80 **To:** 9/30/81
Project/Area/Task: High Efficiency Concentrators
Contract Funding: FY80 $127,279 FY81 $-0- FY $ FY $
Funding Source: SERI

The study is designed to: (1) assess the extent to which the purity and uniformity of presently available metallorganic sources affect the performance of solar cells; (2) determine what, if any, impurities present in commercially available TMGa (Trimethylgallium), TMA1 (Trimethylaluminum), and AsH_3-in-H_2 degrade solar cell performance; (3) establish techniques for removing such impurities; and (4) specify procedures for ensuring availability of metallorganic sources of adequate quality for solar cell manufacture.

Title: Support for PV Performance Criteria and Test Method Development **Contract Number:** 1206-1
Directing Organization: Solar Energy Research Institute
Project Engineer: P. Longrigg/G. Nuss **Telephone:** (303) 231-1181/(303) 231-1287
Contractor: Sandia Laboratories
Division 4719
P.O. Box 5800
Albuquerque, NM 87185
Principal Investigator: H. Post **Telephone:** (505) 844-2154
Contract Period of Performance: **From:** 7/27/81 **To:** 7/27/82
Project/Area/Task: Performance Criteria/Test Methods
Contract Funding: FY81 $50,000 FY $ FY $ FY $
Funding Source: SERI

Tasks assigned under this contract are designed to employ the technical resources of the SLA PV program in support of the SERI PC/TM task. These tasks include:

1. Lead and coordinate SERI's Task Group #3 (Systems).
2. Develop and evaluate interim performance criteria for systems and system interfaces.
3. Document draft test methods referenced in evaluation statements given in the IPC document. This documentation is to follow the test method protocol supplied by SERI.
4. Support the development of code (i.e., fire, electrical, building, etc.) related information, criteria, and tests for the development and/or revision of applicable codes for PV systems. This support most likely will be in the form of reports and/or other information developed in other portions of the TD&A program.

Title:	Fundamental Studies of Grain Boundary Passivation in Polycrystalline Silicon With Application to Improved Photovoltaic Devices	**Contract Number:**	9109-01
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Simon Tsuo	**Telephone:**	(303) 231-7682
Contractor:	Sandia Laboratories Albuquerque, NM 87115		
Principal Investigator:	C. H. Seager/D. L. Ginley	**Telephone:**	(505) 264-9168/(505) 264-8863
Contract Period of Performance:	**From:** 1/1/79 **To:** 6/1/82		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY79 $150,000 FY80 $237,000	FY81 $247,000	FY $
Funding Source:	DOE SERI	SERI	

The object of the program is to investigate whether polycrystalline silicon can be a good solar cell material provided the grain boundaries are passivated. Successful passivation and use of polycrystalline silicon requires understanding of transport and recombination at grain boundaries; a major emphasis is therefore placed on basic studies of electronic transport properties in the presence of grain boundaries.

Passivation is achieved by the introduction of atomic hydrogen to the grain boundaries. Fundamental studies are carried out by a variety of scanning techniques including voltage probes and electron beam induced currents (EBIC) which allow the properties of a single grain boundary to be measured. The resulting grain boundary conductance, capacitance and recombination are related to microscopic properties of the boundary (such as density of states) by a theoretical treatment.

The single grain boundary measurements have been shown to be consistent with a simple theoretical description of grain boundary electronic structure. This model, the double depletion layer/thermal emission (DDL/TE) approach, characterizes the band bending near the grain boundary by a simple symmetric pair of depletion layers, one on either side of the grain boundary plane. The transport properties of this structure are calculated using thermionic emission expressions for current flow over, into, and out of the traps at the grain boundary center. Extensive calculations of the capacitance and conductance have been made, and the agreement observed with experimental measurement of these quantities as a function of frequency, d.c. bias, and temperature is good.

Recent grain boundary passivation studies have shown that polycrystalline silicon solar cell efficiency more than doubled after only four minutes of atomic hydrogen grain boundary passivation treatment. The solar cells studied were made of Honeywell semiconductor-grade silicon-on-ceramic material (about 300 μm thick with millimeter range grain size) with diffused n+p junctions. The efficiencies before grain boundary passivation were typically between 2 and 3% (without AR coating). The efficiencies after grain boundary passivation were between 5 and 7%. A DC plasma system was used in all of these studies. The treatment conditions were 1.2 torr and 5 mA total DC plasma current. The samples were held at 265°C for two minutes and then 488°C for two minutes during the treatments. The device parameters under AM1 conditions for a typical sample (without AR coating) before grain boundary passivation were V_{oc}= 340 mV, I_{sc}=12.7 mA/cm^2, FF=.63 and η= 2.7%. After grain boundary passivation, the parameters were V_{oc}=470 mV, I_{sc}=25.5 mA/cm^2, FF=.55, and η=6.6%.

Title: Amorphous Silicon Integrated Cell Module Design Study
Contract Number: 1227-1
Directing Organization: Solar Energy Research Institute
Project Engineer: L. Mrig
Telephone: (303) 231-1807
Contractor: Science Applications Inc.
1710 Goodridge Drive
P.O. Box 1303
McLean, VA 22102
Principal Investigator: Yudi Gupta
Telephone: (703) 821-4300
Contract Period of Performance: From: 6/19/81 To: 11/19/81
Project/Area/Task: Technical Support/Adv. Systems Research
Contract Funding: FY81 $35,783 FY $ FY $ FY $
Funding Source: SERI

The objective of this project is to investigate and develop amorphous silicon integrated cell module design concepts and to analyze key module design issues and tradeoffs. The conceptual designs will be based on cell circuit configurations as well as cell characteristics and parameters. A minimum of three designs will be developed illustrating the expected optimum performance rating of each module design as well as preliminary cost information.

Emphasis will be placed on cell sizes, geometrics within the module, interconnect schemes, and module performance parameters as related to potential applications.

Title: Casting or Sheet Silicon for Photovoltaic Cells
Contract Number: 9010-8
Directing Organization: Solar Energy Research Institute
Project Engineer: J. Milstein
Telephone: (303) 231-7299
Contractor: Sclamat, Inc.
885 Waterman Avenue
East Providence, RI 029`4
Principal Investigator: M. C. Narasimhan
Telephone: (401) 438-6784
Contract Period of Performance: From: 9/10/80 To: 9/9/81
Project/Area/Task: High Efficiency/Polycrystalline Silicon
Contract Funding: FY80 $76,790 FY81 $-0- FY $ FY $
Funding Source: SERI

This program investigates the production of polycrystalline silicon sheet by casting directly from the melt. The objective is to establish the process parameters which lead to p-optimum silicon sheet properties (mechanical, chemical, structural, and electrical) suitable for fabricating low-cost, high efficiency solar cells.

The optimization of the casting process involves investigation of parameters such as nozzle geometry, gap size and location, surface velocity cr wheel rotation speed, melt temperature, and pressure. The dependence of sheet thickness, width, and grain size on the process parameters have been examined. Problems relating to the interaction of molten silicon with wheels of a variety of compositions (i.e., glass, metals, and ceramic) have been observed, and are not presently completely understood.

Title:	Direct Casting of Sheet Semi-crystalline Silicon	**Contract Number:**	8041-4
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joe Milstein	**Telephone:**	(303) 231-7299
Contractor:	Solarex Corporation 1335 Piccard Drive Rockville, MD 20850		
Principal Investigator:	William F. Regnault	**Telephone:**	(301) 948-0202
Contract Period of Performance:	**From:** 9/15/79 **To:** 9/14/80		
Project/Area/Task:	Polycrystalline Silicon		
Contract Funding:	FY79 $99,260 FY $	FY $	FY $
Funding Source:	SERI		

The object of this research is to demonstrate the formation of sheet silicon for photovoltaic cells by the technique of ambit casting. In this method a mold is brought into contact with molten siiicon and a silicon film is grown on the surface.

The technical approach to be pursued consists of five tasks, which include: (1) formulating an experimental plan, encompassing the definition of equipment, materials, characterization techniques, experimental schedule, and range of process parameters; (2) developing a mathematical analytical model of the thermal environment of the mold and the semicrystalline silicon sheet; (3) assembling and calibrating equipment; (4) carrying out a series of experimental casting; and (5) characterizing and evaluating the semicrystalline sheet silicon produced as to physical, chemical, and electrical characteristics.

The experimental plan was formulated, a thermal analysis was performed, a casting apparatus was assembled and operated, experimental castings were made, and characterization of cast semicrystalline sheet silicon was performed. The mold material of choice has been found to be graphite, growth of sheets under thermal transient conditions has been demonstrated, and a report of characterization results was completed. It has been found that grains ranging in area up to 5 mm^2 could be grown. Crystallographic measurements have demonstrated that most grains are heavily twinned. The theoretical thermal analysis was performed assuming steady state thermal conditions, which is not the case in the experimental method as performed in this work. While the thermal analysis is interesting, its value in explaining the experimental data must be questioned. A time dependent thermal analysis, which would be of greater value, is exceedingly difficult to perform.

Title: Investigation of the Impurity Tolerance of Semicrystalline Silicon Solar Cells
Contract Number: 8272-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Joseph B. Milstein
Telephone: (303) 231-7299
Contractor: Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
Principal Investigator: George Storti
Telephone: (301) 948-0202
Contract Period of Performance: From: 10/1/78 To: 10/31/80
Project/Area/Task: Polycrystalline Silicon Program

	FY78	FY79	FY80	FY81
Contract Funding:	$149,339	$248,046	$109,215	$5,614
Funding Source:	DOE	SERI	SERI	SERI

This program is designed to provide a scientific basis for understanding the relationship between the key parameters for the formation of cast polycrystalline silicon material, utilizing a mixture of metallurgical (MG) and semiconductor grade (SG) silicon as a feedstock, and the resulting photovoltaic material characteristics.

Four tasks have been identified to meet the program goals:

1. Design and assemble a casting station to allow the reproducible and in situ casting of polysilicon ingots by unidirectional solidification.
2. Prepare and characterize a uniform feedstock of metallurgical grade silicon, and perform experimental castings using various ratios from 0 to 10% MG to SG silicon under various thermal solidification conditions.
3. Fabricate solar cells to characterize the material electrically and use these results to direct later casting experiments.
4. Perform theoretical and experimental investigations of grain and grain boundary effects to relate the structural and electrical characteristics of polysilicon solar cells.

Forty-seven casting runs have been performed including MG silicon percentages of 0, 1, 5, and 10%, and solidification rates of 1, 2, and 5 cm/hr. Grain size typically increased from bottom to top of the ingots varying from approximately 0.5 mm at the bottom to 1.5 mm at the top of the casting. Maximum efficiencies of 11.1% AMO (nearly 13% AM1) were obtained for cells fabricated on wafers from 100% SG ingots. Average cell efficiencies decreased from approximately 10% AM1 (100% SG silicon) to less than 5% AM1 at 10% MG silicon levels. Typically, cell efficiencies were best on wafers taken from the top of the ingot, middle cells were next, and bottom cells were the lowest. Cell efficiencies were degraded by low short-circuit current primarily due to a reduced minority carrier diffusion length within the grains and by grain boundary recombination to a smaller extent for cells made on bottom wafers. Further loss in efficiency resulted from the domination of the dark I-V characteristics by a large space-charge component which degrades the fill factor and open circuit voltage. Grain and grain boundary effects have been studied using photoresponse scanning, Deep Level Transient Spectroscopy, SEM, electron channelling, x-ray diffraction, and x-ray topography. Scanning photoresponse patterns have been matched with x-ray topographs to show the effect of the microstructural features (dislocations, inclusions, sub-grain boundaries and twin traces) on the photoresponse. Decreases in photoresponse at grain boundaries are attributed to the dislocation content at the boundary interface (which changes with the position of the boundary) needed to make up a portion of the mismatch between adjacent grain orientations.

Title:	Thin Film Gallium Arsenide Solar Cell Research	**Contract Number:**	9002-3
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Benner	**Telephone:**	(303) 231-1396
Contractor:	Southern Methodist University Dallas, TX 75275		
Principal Investigator:	Shirley S. Chu	**Telephone:**	(214) 692-3024
Contract Period of Performance:	**From:** 11/30/79 **To:** 2/27/82		
Project/Area/Task:	Thin Film Gallium Arsenide		
Contract Funding:	FY79 $185,740 FY81 $193,017	FY $	FY $
Funding Source:	DOE SERI		

The objective of this research is to produce GaAs solar cells of 10% conversion efficiency in films less than 10 micrometers thick which have been deposited by CVD on graphite or tungsten-coated graphite substrates.

The principal approach used in this program is the deposition of gallium arsenide films on low-cost substrates by the reaction of gallium, hydrogen chloride, and arsine in a hydrogen flow system. Tungsten coated graphite has been used as the substrate for the deposition of gallium arsenide films. The MOS approach has been used for thin film gallium arsenide solar cells. Subsequent to the deposition process, the gallium arsenide film was oxidized insitu with oxygen at 200°C. In some cases, the in situ oxidation was followed by oxidation with water vapor at room temperature. A gold or silver film of 600-1000 Å thickness was evaporated onto the surface to form the Schottky barrier, and the silver grid contact was also formed by evaporation. The use of a thin layer of higher energy gap material, gallium phosphide or aluminum arsenide at the surface of gallium arsenide film has been under investigation with the objective of increasing the open-circuit voltage of the MOS device. The antireflection coating will be carried out by depositing titanium dioxide, tantalum pentoxide, or other oxides by the ion beam coating technique.

At present the best MOS polycrystalline GaAs solar cells are 8.5% efficient for cells with a total area of 9 cm^2. Preliminary experiments with pn junctions have produced cells of 7.1% efficiency over 8 cm^2 area.

Title:	Thin Film Cadmium Telluride and Zinc Phosphide Solar Cells	**Contract Number:**	9286-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Southern Methodist University Dallas, TX 75275		
Principal Investigator:	Ting Chu	**Telephone:**	(214) 692-3014
Contract Period of Performance:	**From:** 7/1/79 **To:** 5/31/82		
Project/Area/Task:	Compound Semiconductor/Emerging Matls.		
Contract Funding:	FY79 $140,730 / FY80 $130,000 / FY81 $150,000 / FY $		
Funding Source:	DOE / SERI / SERI		

The objectives of this project are to conduct research and development of thin film polycrystalline cadmium telluride and zinc phosphide solar cells on low cost substrates and to demonstrate the feasibility of producing thin film cells with a conversion efficiency of 10% or higher.

The technical approaches consist of the chemical vapor deposition of cadmium telluride and Zn_3P_2 films on graphite and coated graphite substrates, the control of conductivity type and carrier concentration in deposited cadmium telluride films, the characterization of electrical and structural properties of cadmium telluride films, and the fabrication and characterization of MOS type thin-film cadmium telluride solar cells.

P-type cadmium telluride films 20 μm thick have been deposited on tungsten/graphite, bismuth/tungsten/graphite, lead/tungsten/graphite and lead telluride/tungsten/graphite substrates. Elemental antimony and phosphorus were used as dopants. Resistivities in the range of 50-200 ohm-cm have been obtained with grain sizes up to 20 micrometers.

1 cm^2 Schottky barrier cells fabricated on these films have η=5.2% with best cell parameters of V_{oc}=420 mV; J_{sc}=22mA/cm^2 and FF=.60.

Zinc phosphide films, as identified by x-ray diffraction, have been deposited on steel substrates. The films are p-type with resistivities ranging from 150 to 250 Ω-cm; hole mobilities of 1-2 cm^2/V-sec and carrier concentrations in the 10^{15} - $10^{16} cm^{-3}$ range. Devices fabricated from these films show 2% efficiency.

Title:	Epitaxial Solar Cell Service	**Contract Number:**	1172-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Simon Tsuo	**Telephone:**	(303) 231-7682
Contractor:	Spire Corporation Bedford, MA 01732		
Principal Investigator:	Robert Wolfson	**Telephone:**	(617) 275-6000
Contract Period of Performance:	**From:** 6/1/81 **To:** 12/1/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY81 $25,000 / FY $ / FY $ / FY $		
Funding Source:	SERI		

The objectives of this program are to prepare thin epitaxial silicon films by the chemical vapor deposition technique on metallurgical-grade polycrystalline silicon substrates supplied by SERI, and to subsequently fabricate solar cells by p-n junction diffusion or by ion-implantation and annealing techniques. These p-n junction solar cells will be compared against the performance of MIS, SIS, and MIS-IL cells fabricated by other SERI subcontractors on identical epitaxial silicon films prepared by Spire.

CVD epitaxial silicon films 40 μm on mg-silicon substrates have been made with resistivities ranging from 2 ohm-cm to 200 ohm-cm. P-n junction solar cells with AM1 efficiencies up to about 11.3% have been made on these substrates.

Title:	Preparation of Germanium-on-Silicon Substrates for Gallium Arsenide Solar Cells by Electron Beam Processing	**Contract Number:**	9002-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Benner	**Telephone:**	(303) 231-1396
Contractor:	Spire Corporation Patriots Park Bedford, MA 01730		
Principal Investigator:	S. P. Tobin	**Telephone:**	(617) 275-6000
Contract Period of Performance:	**From:** 3/15/80 **To:** 1/14/82		
Project/Area/Task:	Thin Film Gallium Arsenide		
Contract Funding:	FY80 $164,260	FY81 $155,300	FY $ FY $
Funding Source:	SERI	SERI	

The goal of this research is to develop very high efficiency thin film GaAs solar cells by obtaining nearly single crystalline films of GaAs heteroepitaxially grown on germanium-coated silicon substrates. Electron beam pulse processing techniques are employed for enhancement of crystalline quality of the Ge/Si substrates. Currently an MO-CVD reactor is under construction for deposition of GaAs layers.

Title:	Investigation of Photoelectrochemical Corrosion of Semiconductors	**Contract Number:**	8002-6
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	SRI International 333 Ravenswood Avenue Menlo Park, CA 94025		
Principal Investigator:	K. W. Frese, Jr.	**Telephone:**	(415) 326-6200
Contract Period of Performance:	**From:** 4/15/79 **To:** 3/14/82		
Project/Area/Task:	Polycrystalline Thin Films/ Photoelectrochemistry		

Contract Funding:	FY79 \$116,713	FY80 \$128,425	FY81 \$132,945	FY \$
Funding Source:	SERI	SERI	SERI	

The objective of this project is to study the influence of defects such as dislocations and grain boundaries on the photoelectrochemical corrosion of GaAs, CdTe, and Si. Additionally, redox couples and surface pretreatments will be sought that suppress such corrosion.

The approaches which will be used include:

a) Measure corrosion rates on ideal single crystals.
b) Produce defective single crystals with dislocations and surface steps. Obtain polycrystalline material to measure grain boundary effects.
c) Measure and compare corrosion rates on ideal and defective surfaces.
d) Vary redox levels in solution to alter competition between corrosion and hole exchange with solution.
e) Look for redox couples that stabilize defective surfaces.
f) Corrosion measurements will be made with the rotating ring-disc electrode.
g) A theoretical modeling of decomposition potentials for defective surfaces.

The current status of the program includes the following accomplishments:

- The effects of concentration, pH, and light intensity on the stabilization efficiency were studied for Fe(II) EDTA and hydroquinone on well-etched GaAs.
- The effect of fractional monolayers of deposited noble metals as stabilizing agents on GaAs was investigated and a strong effect observed.
- Various redox couples were tried to determine which would effectively suppress the photocorrosion of n-CdSe. The stabilizing effect of the $Fe(CN)_6^{-4/-3}$ redox couple was studied as a function of pH. The electrochemical behavior of n-CdSe modified with selenium surface films was examined. An efficiency of 12.4% was obtained for single crystal n-CdSe in an aqueous $Fe(CN)_6^{-4/-3}$ electrolyte.

Title:	Sprayed $CdS/CuInSe_2$ and Sintered CdTe Low-Cost Solar Cells	**Contract Number:**	8104-4
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	A. Hermann	**Telephone:**	(303) 231-1311
Contractor:	SRI International Menlo Park, CA 94025		
Principal Investigator:	John Mooney	**Telephone:**	(415) 326-6200, X2906
Contract Period of Performance:	**From:** 9/1/79 **To:** 2/28/82		
Project/Area/Task:	Emerging Materials		
Contract Funding:	FY79 $173,309 FY80 $97,820	FY81 $243,292	FY $
Funding Source:	SERI SERI	SERI	

The objectives of the proposed continuation effort include: (1) continuation of the development and characterization of chemically sprayed CdS, $CuInSe_2$, and $Cd_xZn_{1-x}S$ films and sintered layers of CdS and CdTe; (2) continuation of analysis of thermodynamics, chemical kinetics, and device physics of the various layers and junctions; (3) development and characterization of solar cells formed by chemical spray and sintered film techniques with an analysis of the mechanisms which control the photocurrent and junction rectification and limit the photovoltaic efficiency.

In order to meet the above objectives the following four areas need to be addressed:

1) Fabricate solar cell devices using p-$CuInSe_2$/CdS and p-$CuInSe_2/Cd_xZn_{1-x}S$ layers formed by spray pyrolysis.
2) Fabricate devices from sintered CdS and CdTe layers.
3) Characterize the above layers with reference to chemical, physical, and electrical properties.
4) Characterize the above devices electrically in order to optimize the output.

Spray pyrolysis cadmium sulfide films with a resistivity less than 1Ω-cm have been deposited. An all sprayed $CdS/CuInSe_2$ heterojunction has been fabricated. This device had $V_{oc} = 0.33V$ and $J_{sc} = 20$ mA/cm^2 at 150 mW/cm^2. A study of basic thermodynamic influences on film growth has been completed yielding significant improvements in $CuInSe_2$ film quality.

Sintered cadmium telluride/cadmium sulfide cells show a V_{oc} of 560 mV and $J_{sc} \ll 1$ mA/cm^2.

Title:	Electrochemical Characterization of Polycrystalline Thin Films for Solar Cells	**Contract Number:**	9307-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Joseph B. Milstein	**Telephone:**	(303) 231-7299
Contractor:	SRI International 333 Ravenswood Avenue Menlo Park, CA 94025		
Principal Investigator:	S. Roy Morrison	**Telephone:**	(415) 326-6200, X3868
Contract Period of Performance:	**From:** 7/28/79 **To:** 7/27/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY79 $98,331	FY80 $104,412	FY81 $-0- FY $
Funding Source:	DOE	SERI	

The objective of this investigation is to use the techniques of semiconductor electrochemistry to characterize grain boundaries and dislocations in silicon. Thin layers of polycrystalline semiconductors will undoubtedly be used for practical solar cells. Good methods of characterizing such layers are needed now for research and, later, for quality controls. Because of the difficulties associated with the grain boundaries in interpreting conductance or photoconductance measurements parallel to the layers, it is concluded that studies of the Schottky barrier, where the voltage is applied normal to the layer, provide the most promising technique for easy measurement of diffusion length, dopant density, and the properties and density of active grain boundaries in the layer.

The measurement of capacity/voltage and current/voltage using an electrochemical Schottky barrier, rather than a metal/semiconductor Schottky barrier, has many advantages. It is nondestructive and easy to apply. Current flow can be blocked by using an indifferent electrolyte, so that grain boundary leakage currents are minimized and the space charge capacity is monitored easily. Finally, current flow can be induced at will by introducing active ions for studies of grain boundary leakage. Thus, for example, such characteristics as conducting bands in the grain boundaries can be detected by noting the energy level of ions in solution that can exchange carriers with these bands.

The program is in two parts. One is the generation of recipes for electrolyte solutions that can be used for reliable measurement of doping level and diffusion length. The second is the study of current flow between certain ions in solution and grain boundaries, where such current flow will be used to characterize the grain boundaries in terms of their deleterious effect on solar cell performance. At the present time apparently reliable techniques have been developed for L_p and doping level measurement, but further tests are needed. Significant current flow associated with grain boundaries is noted, and conceivably one could use the magnitude of the current to monitor the perfection of the layers. A method for decorating grain boundaries by the use of various metals dissolved in the electrolyte has also been observed, but has not been fully characterized.

Title:	Fundamentals of Semiconductor Surfaces and Interfaces in Relation to Solar Energy Conversion Devices			**Contract Number:**	1181-1		
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	S. Deb			**Telephone:**	(303) 231-1105		
Contractor:	Stanford University Electronic Laboratory Stanford, CA 94305						
Principal Investigator:	W. Spicer						
Contract Period of Performance:	**From:** 5/1/81 **To:** 4/30/82						
Project/Area/Task:	Solar Cell R&D						
Contract Funding:	FY81 $93,941	FY	$	FY	$	FY	$
Funding Source:	SERI						

The Au on clean GaAs (110) experiments will be reproduced and extended to higher Au overlayer thickness until the pinning position is found to stabilize. If the stabilization point is not that of maximum barrier height on n-type material, emphasis will be placed on determining and studying the conditions for obtaining maximum barrier height n-type GaAs.

The effect of annealing at various temperatures as well as evaporation on cooled GaAs will be studied as a function of the amount of Au deposited.

The effect of prior oxygen coverage from sub to many monolayers of oxygen will be studied. The chemistry as well as the thickness of the oxide will be considered.

Au is thought to associate or attach itself to defect sites in the crystal lattice. The role of defect sites (in the absence of adsorbates other than Au) in the Au-GaAs system will be investigated by introducing defects prior to depositing Au, and then monitoring the pinning position as Au is deposited.

The core levels of both the Au and GaAs will be studied on n- and p-type GaAs to attempt to detect and understand any chemical interactions taking place.

Other transition metals on GaAs are being studied. Both the pinning position and the stability of the Schottky barrier may be strong functions of interfacial reactions (particularly compound formation). We may test our understanding of the pinning mechanism by depositing different transition metals on GaAs.

Models will be developed for the observed phenomena.

The above experiments will be repeated on other surfaces (for example, the (110) and (100) surfaces) cleaned by heating, sputtering and annealing, or other means. This will involve considerable work in cleaning the surfaces by means other than cleaving; however, it is clearly essential from both the basic and practical points of view.

Diodes will be fabricated on which conventional I-V and other electrical measurements will be made for comparison with practical devices.

Title: Photoelectronic Properties of Zinc Phosphide Crystals, Films, and Heterojunctions — **Contract Number:** 1202-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Allen Hermann — **Telephone:** (303) 231-1311
Contractor: Stanford University
Dept. of Materials Science and Engineering
Stanford, CA 94305
Principal Investigator: Richard H. Bube — **Telephone:** (415) 497-2951
Contract Period of Performance: **From:** 2/26/79 **To:** 1/31/83
Project/Area/Task: Emerging Materials

Contract Funding:	FY79 $109,013	FY81 $151,962	FY $	FY $
Funding Source:	SERI	SERI		

The purpose of this research program is to investigate the photoelectronic properties of zinc phosphide (Zn_3P_2) in single crystal form, in thin-film form, and in heterojunctions in which Zn_3P_2 forms one of the elements. This research is directed toward understanding the role of crystalline defects and impurities in Zn_3P_2, the nature of the electronic charge transport in single crystal and thin-film material, and the properties of photovoltaic heterojunctions involving Zn_3P_2.

Enhanced nucleation and faster transport rate were confirmed after pre-growth baking of the quartz ampoule in vacuum was carried out to reduce the residual gases in the ampoule during growth. Enhanced growth rate of single crystal Zn_3P_2 was also achieved by using iodine as a chemical transport agent. Both source and crystal growth temperatures could be reduced while maintaining the growth rate. Electrical measurements of the chemical-transport grown Zn_3P_2 indicate p-type conductivity of about the same magnitude at 300° K as in crystals grown by sublimation in the sealed tube method, thus indicating that iodine does not play an appreciable role as donor impurity.

A research effort on photoluminescence in Zn_3P_2 single crystals has been completed. The results show that sublimation-grown crystals exhibit two main luminescence peaks at 1.361 and 1.354 eV at 2.5° K, each of which has phonon replica displaced by 43 eV, and a third smaller peak observable only above 20° K at 1.367 eV. Iodine-transport grown crystals show a broad peak at 2.5° K at 1.320 eV and its phonon energy for peak emission shifts with excitation intensity as is typical of pair transitions for the major bands as seen at 2.5° K. Temperature dependence measurements identify donor and acceptor ionization energies corresponding to the observed bands.

Title:	Fundamental Studies of Photocarrier Tunneling in GaAs Thin Film Solar Cell Structures	**Contract Number:**	8030-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	J. Benner	**Telephone:**	(303) 231-1396
Contractor:	Stanford University Stanford, CA 94305		
Principal Investigator:	G. L. Pearson	**Telephone:**	(415) 497-4680
Contract Period of Performance:	**From:** 3/19/79 **To:** 8/18/81		
Project/Area/Task:	Thin Film Gallium Arsenide		
Contract Funding:	FY79 $84,454 FY81 $-0-	FY $	FY $
Funding Source:	SERI		

The objective of this contract is to increase the efficiency of heterojunction Schottky barrier solar cells by optimizing minority carrier (photocarrier) transport mechanisms.

The technical approach in this project consists of the following:

a. Identify the role that carrier tunneling plays in p-n heterojunction transport.

b. Identify the role of minority carriers in transport at a Schottky barrier.

c. Fabricate Schottky barrier solar cells optimized for minority carrier transport.

Analysis of p-n heterojunctions which were fabricated with tunneling as the primary transport mechanism has shown that heterojunction grading reduced the effect of the hole barrier on device performance.

Title:	Photovoltaic Heterodiodes Based on Indium Phosphide	**Contract Number:**	8087-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Leon Fabick	**Telephone:**	(303) 231-1311
Contractor:	Stanford University Material Science and Engineering Department Stanford, CA 94305		
Principal Investigator:	Richard H. Bube	**Telephone:**	(415) 497-2534
Contract Period of Performance:	**From:** 4/1/79 **To:** 9/30/82		
Project/Area/Task:	Polycrystalline Thin Films Program		
Contract Funding:	FY79 $51,280 FY80 $116,260	FY81 $14,000	FY $
Funding Source:	SERI SERI	SERI	

This program concerns a detailed study of heterodiode solar cells based on indium phosphide. Included are the preparation and characterization of such heterodiodes as well as the establishment of detailed device physics models. The long-range goal of this work is the development of optimized growth techniques and of a quantitative description of these heterodiodes, both in support of the preparation of highly efficient solar cells.

Two InP-based heterodiode cells have reached efficiencies of about 15%, the limit imposed by the quality of presently available InP bulk crystals. These are the closely lattice-matched p-InP/n-CdS, and the apparently highly mismatched p-InP/n-indium tin oxide glass diode. This unique situation suggests that a detailed study of these devices could answer the question whether and to what extent lattice-match is required for an efficient heterodiode cell.

Title:	Photovoltaic Heterodiodes Based on Indium Phosphide		**Contract Number:** 8087-1	
Directing Organization:	Solar Energy Research Institute			
Project Engineer:	Leon Fabick		**Telephone:** (303) 231-1311	
Contractor:	Stanford University Material Science and Engineering Department Stanford, CA 94305			
Principal Investigator:	Richard H. Bube		**Telephone:** (415) 497-2534	
Contract Period of Performance:	**From:** 4/1/79 **To:** 9/30/82			
Project/Area/Task:	Polycrystalline Thin Films Program			
Contract Funding:	FY79 $51,280	FY80 $116,260	FY81 $14,000	FY $
Funding Source:	SERI	SERI	SERI	

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Title: Preparation and Properties of Evaporated CdTe Films Compared with Single Crystal CdTe
Contract Number: 9330-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Allen Hermann **Telephone:** (303) 231-1311
Contractor: Stanford University
Department of Materials Science and Engineering
Stanford, CA 94305
Principal Investigator: Richard H. Bube **Telephone:** (415) 497-2951
Contract Period of Performance: **From:** 9/29/80 **To:** 10/30/82
Project/Area/Task: Emerging Materials/Compound Semiconductors
Contract Funding: FY81 $160,646 FY $ FY $ FY $
Funding Source: SERI

This program is involved with basic research on single crystal and thin-film CdTe. Doping effects with P, As, Sb, Cs, In and grain boundary effects are being investigated with single crystal CdTe. The hot-wall vacuum evaporation technique is being implemented to deposit thin film CdTe layers.

Growth of large grain polycrystalline (1 cm) CdTe doped with phosphorus indicates a phosphorus electrical activity of 1 rather than 0.1 as previously reported. Growth with excess Cd gives slightly higher doping concentrations than with excess Te. Preliminary results with As are similar. Grain boundary resistivities in the 1-10-cm n-type samples have area resistivity between 10^3 and 10^4 ohm-cm; in the 0.2-0.5 ohm-cm n-type samples the values are lower at 0.5-48 ohm-cm. Thermal activation energies of the grain boundary dark resistivity are between 0.25 and 0.65 eV. Illumination decreases the resistivity and the activation energy, while increasing the capacitance of the grain boundary.

Hot-wall vacuum evaporation (HWVE) is a technique which allows the decoupling of the thermodynamic and kinetic deposition parameters. This will allow deposition of CdTe thin films under optimum growth conditions. Presently Stanford University has designed and built an HWVE system based on the work of A. Lopez-Otero at the University of Linz, Austria. Thin films of CdTe will be evaporated shortly.

Title:	Fabrication and Testing of MIS Solar Cells on Amorphous Si:F:H	**Contract Number:**	8041-9
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	F. Jeffrey	**Telephone:**	(303) 231-7036
Contractor:	State University of New York-Buffalo Department of Electrical Engineering 4232 Ridge Lea Road Amherst, NY 14226		
Principal Investigator:	Wayne Anderson	**Telephone:**	(716) 831-3166
Contract Period of Performance:	**From:** 9/15/79 **To:** 8/31/82		
Project/Area/Task:	Advanced Silicon/Amorphous Materials		
Contract Funding:	FY79 $54,109	FY80 $52,346	FY81 $29,177 FY $
Funding Source:	SERI	SERI	SERI

The purpose of this program is to fabricate and test low-cost hydrogenated amorphous silicon solar cells. This project is being approached by analysis and design considerations of a-Si:H solar cell operation. Design consideration involves understanding the effects of three components of thin film solar cells; the a-Si:H film, the substrate and thin metal films as a top electrode. Analysis of the device is made to identify the current collection mechanism and to find the cause of the discrepancy between the theoretical limit and experimental results.

Hydrogenated amorphous silicon (a-Si:H) p-n junction solar cells have been fabricated which utilize various metals (Cr, Cu, Al, Pd, Ag) as a top electrode. Experimental and theoretical analysis of photovoltaic performance in a-Si:H solar cells as a function of resistivity, optical transmittance, and work function of thin metal films are presented. Metal work function changes the effective built-in potential of p-n junction diodes. Furthermore, a lower work function metal forms a good ohmic contact for substrate -P^+-I-N^+-electrode cells, and high work function metals improve V_{oc}. Typical values are 760 mV with Cr, Cu and Al-N-I-P-stainless steel, 700 mV with Pd-N-I-P-SS, 600 mV with Pd-P-I-N-SS and 540 mV with Cr-P-I-N-SS. J_{sc} is strongly dependent on transmittance and resistivity of the metal films. Fill factor is independent of the choice of a top electrode. An efficiency of 2% has been obtained on a 2 cm^2 solar cell.

Title:	Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research	**Contract Number:**	8033-2
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Telic Corporation 1631 Colorado Ave. Santa Monica, CA 90404		
Principal Investigator:	John A. Thornton	**Telephone:**	(213) 828-7449
Contract Period of Performance:	**From:** 2/26/79 **To:** 12/1/81		
Project/Area/Task:	Compound Semiconductor/Cadmium Sulfide		

Contract Funding:	FY79 \$149,504	FY80 \$317,582	FY81 \$1,800	FY \$
Funding Source:	SERI	SERI	SERI	

Objective: To investigate and evaluate the application of cylindrical-post and planar magnetron reactive sputtering for the production of solar cell quality thin films of Cd(Zn)S/Cu_2S and Cu_2(Zn)S/Cu $InSe_2$.

Approach: The approach can be described in terms of the following tasks:

1. A modification of the deposition apparatus for three-source sputtering of $CuInSe_2$.
2. An investigation of the use of In doping to control the resistivity of the Cd(Zn)S layer.
3. An investigation of the use of off-stoichiometric deposition or post deposition heat treatment to control the resistivity of the Cd(Zn)S layer.
4. An investigation of the optimum method for depositing the Cu_2S layer.
5. An investigation of all sputter deposited Cd(Zn)S/Cu_2S solar cell structures formed on glass substrates.
6. Interact with subcontractors (Institute of Energy Conversion and Lockheed) to develop hybrid cell using sputtering and evaporation methods.

Status: Coatings are being deposited by reactive sputtering from metal targets (Cu, Cd, Cd doped with In and/or Zn) in an Ar-H_2S working gas. Cd(Zn)S resistivity control has been demonstrated using both In doping and off-stoichiometric deposition (pulsed H_2S flow). Sputtered CdS films can be made with resistivities and photoluminescent properties that are comparable to that of evaporated films. As a result all sputtered cells with $\eta \simeq 3\%$ and $J_{sc} \geq 10$ mA/cm^2 are being made on a reproducible basis. The highest efficiency device is a hybrid cell made with sputtered Cu_2S and evaporated (Cd,Zn)S. It is a 1 cm^2 cell with $\eta = 7.2\%$.

Title:	Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research by Sputter Deposition	**Contract Number:**	9296-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Telic Corporation 1631 Colorado Ave. Santa Monica, CA 94304		
Principal Investigator:	John A. Thornton	**Telephone:**	
Contract Period of Performance:	**From:** 9/2/80 **To:** 11/3/81		
Project/Area/Task:	CdS/Cu_2S Solar Cell Research		
Contract Funding:	FY80 $310,037 FY $	FY $	FY $
Funding Source:	SERI		

Task 1—INCREASE SHORT CIRCUIT CURRENT

This task involves examining the effectiveness of various procedures for increasing the short circuit current. The procedures to be tried will include (1) using graded doping concentrations in CdS films; (2) using uniform CdS films with improved properties and conductivity control by doping and off-stoichiometric deposition; (3) etching of CdS surface in HCl prior to Cu_2S deposition; (4) using post-deposition in situ heat treatments of CdS films prior to Cu_2S deposition; (5) using post-deposition in situ heat treatments of CdS/Cu_2S heterojunctions; (6) forming hybrid cells by depositing Cu_2S onto sputtered CdS using the ion exchange processes; and (7) using techniques such as photoluminescence and scanning electron microscopy to evaluate and compare sputter-deposition and evaporated CdS.

Task 2—OPTIMIZE Cu_2S DEPOSITION

This task involves attempting to establish optimum conditions for the Cu_2S deposition. Attention will be given to determining the optimum thickness for the Cu_2S. This task will be performed in conjunction with Task 1 to achieve efficient solar cells. Particular attention will be given to comparing and contrasting the characteristics of Cu_2S produced by sputtering and by the ion exchange methods.

Task 3—IMPROVE DEVICE DESIGN

This task involves making improvememnts in the basic device design. It will be undertaken once short circuit currents $>10\ mA/cm^2$, as specified in Task 1, have been achieved. The task will include examining the effects of better top grid electrodes and antireflection coatings. Quantitative photon economy analysis will be made to evaluate improvements and to identify approaches for achieving further improvements.

Title:	Thin-Film Polycrystalline Silicon Grain Boundary Characterization and Passivation and MIS Stability and Viability Studies	**Contract Number:** 9080-1		
Directing Organization:	Solar Energy Research Institute			
Project Engineer:	R. W. Hardy	**Telephone:** (303) 231-1482		
Contractor:	State University of New York at Buffalo Department of Electrical Engineering 4232 Ridge Lea Road Amherst, NY 14226			
Principal Investigator:	W. A. Anderson	**Telephone:** (716) 831-3166		
Contract Period of Performance:	**From:** 1/1/79 **To:** 3/3/82			
Project/Area/Task:	High Efficiency/Polycrystalline Silicon			
Contract Funding:	FY79 $60,000	FY80 $109,400	FY81 $80,039	FY $
Funding Source:	DOE	SERI	SERI	

The objectives of this work are to: (1) advance the state of the art in grain boundary characterization and passivation; (2) conclusively demonstrate the stability or lack thereof for MIS solar cells; and (3) optimize the Cr/MIS solar cell design.

Measurements of C-V and G-V curves for diodes fabricated on grain boundaries yield calculated interface state densities of $5 \times 10^{11}/cm^2$ eV. These results are correlated with resisitivity and photovoltaic measurements to demonstrate the detrimental effect of thermal cycling and the nearly complete restoration of the original state by hydrogen passivation. These data together with temperature dependent data are being fit to grain boundary models to gain insight into the basic mechanisms involved.

The only instability/degradation mechanism identified to date has been the reduction of the oxide layer by the chromium in the Cr/MIS cell. This has been remedied by using a slightly thicker oxide layer so that the desired oxide thickness is obtained after equilibrium is established with the chromium.

Optimization of the Cr/MIS cell is nearly complete. An optimum grid has been ordered for the sheet resistivities obtained. Adaption of one of the available AR coatings remains to be done.

Title:	Drift Mobility in Amorphous Silicon	**Contract Number:**	1240-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Tulane University Department of Physics New Orleans, LA 70118		
Principal Investigator:	R. D. Purrington	**Telephone:**	
Contract Period of Performance:	**From:** 7/1/81 **To:** 6/30/82		
Project/Area/Task:	Innovative Concepts		
Contract Funding:	FY81 $10,400 FY $	FY $	FY $
Funding Source:	SERI		

Contract objectives are as follows:

1. Drift mobility studies will be performed on varying-composition amorphous silicon films. Films produced at SERI will be studied as will be films obtained from subcontractors.
2. The influence of composition (H, F) on dispersive vs. nondispersive transport will be evaluated. The effects of varying temperature, applied voltage, and film thickness will be evaluated.
3. Amorphous silicon solar cell structures will be studied both by transient photoconductivity and by illuminated IV characteristics. Comparisons between characteristics in the dispersive transport regime and those in the nondispersive regime will be made.

Films of varying thicknesses have been formed at SERI using RF glow discharge of silane. Preliminary characterization of the films is in progress. Transient photo-conductivity apparatus is expected to be fully functional within two months.

Title:	Integrated Material/Device Approach for Cu_2S/CdS Solar Cells	**Contract Number:**	9010-9
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	A. Hermann	**Telephone:**	(303) 231-1311
Contractor:	UCLA Department of Materials Science and Engineering Los Angeles, CA 90024		
Principal Investigator:	R. F. Bunshah	**Telephone:**	
Contract Period of Performance:	**From:** 5/1/80 **To:** 7/31/81		
Project/Area/Task:	Innovative Concepts		
Contract Funding:	FY80 $90,459 FY81 $-0-	FY $	FY $
Funding Source:	SERI		

The main objective of the proposed program is to develop a low-cost integrated materials/solar cell approach for fabrication of Cu_2S/CdS thin film solar cells. The approach comprises: 1) investigating the preparation and properties of Cu_2S, CdS film of controlled stoichiometry by the Activated Reactive Evaporation (ARE) process: 2) investigating the fabrication, characterization, and optimization of thin film Cu_2S/CdS solar cells in a cell geometry which overcomes many of the degradation effects commonly encountered in such cells prepared by conventional techniques. The ARE process would also allow the fabrication of solar cells in a sequential all vacuum process.

Deposition of single-phase chalcocite Cu_2S films of resistivity 10^{-2} ohm-cm has been achieved using the ARE process. CdS/Cu_2S devices fabricated using these films and directly evaporated CdS have demonstrated $V_{oc} \sim 350$ mV, $I_{sc} \sim 1$ mA, and FF = 0.25.

Title:	Development of Proposed Revisions/Additions to the National Electrical Code for PV Systems	**Contract Number:**	9429-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	P. Longrigg	**Telephone:**	(303) 231-1183
Contractor:	Underwriters Laboratories 333 Pfingsten Road Northbrook, IL 60062		
Principal Investigator:	P. Dukes	**Telephone:**	(312) 272-8800
Contract Period of Performance:	**From:** 10/6/80 **To:** 10/30/81		
Project/Area/Task:	Performance Criteria/Test Methods		
Contract Funding:	FY81 $75,856 FY $	FY $	FY $
Funding Source:	SERI		

In order to secure timely and economic deployment of domestic/residential PV systems, it is necessary that building/fire codes and other standards do not present an impediment to this. As presently written and interpreted, many important codes and standards will present such an impediment. One code of vital importance is the National Electrical Code (NEC), and it will be necessary to amend existing sections and/or add a further section specific to PV safety, in the 1984 edition of the code.

Under this contract specific articles of amendment, technical recommendations, and support documentation were developed for inclusion, after due process, in the 1984 edition of the NEC. The articles of amendment are concerned with the safe installation and operation of terrestrial solar residential photovoltaic (PV) systems.

The work of this subcontract involved a thorough analysis of the latest edition of the NEC. This analysis identifies those sections of the code and their commonly accepted interpretations that may be considered applicable to the safe deployment of PV systems. Each code article that appears to have any relevance to PV deployment was examined critically, and where considered necessary, changes and amendments, together with justifications, were prepared for submission to the NFPA/NEC-PV subcommittee.

A completely new draft article (6XX), with substantiations, has been completed for PV systems safety. This article will be considered by the NEC panels for inclusion in the 1984 NEC.

Title:	Investigation of Nonaqueous Regenerative Photoelectrochemical Cells
Contract Number:	9178-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	William Wallace
Telephone:	(303) 231-1380
Contractor:	SumX Corporation 1300 E. Braker Lane P.O. Box 14864 Austin, TX 78761
Principal Investigator:	David DeBerry
Telephone:	(512) 835-0330
Contract Period of Performance:	**From:** 4/15/80 **To:** 8/31/81
Project/Area/Task:	Polycrystalline Thin Films/Photoelectrochemistry
Contract Funding:	FY80 $144,923 FY81 $8,319 FY $ FY $
Funding Source:	SERI SERI

The objective of the proposed program is the characterization of the behavior of semiconductors in nonaqueous solvent/redox couple systems which are potentially usable in regenerative (liquid junction) photoelectrochemical cells (PECs) and the minimization or elimination of the degradation processes which inherently limit cell performance in terms of stability and efficiency. Such an effort requires the investigation and optimization of electrolytes and semiconductors. Enhanced stability may also allow modifications to obtain higher energy conversion efficiencies.

Three principal tasks form the basis of this study; these tasks are: (1) semiconductor/solvent screening; (2) second stage screening in the presence of redox couples; and (3) efficiency and extend degradation tests. Task 1 involves the determination of the key characteristics of approximately 50 combinations of n-type semiconductors and aprotic solvents. Task 2 will characterize approximately ten of the most favorable combinations from Task 1 when coupled with redox systems. Task 3 will involve determining the solar energy conversion efficiencies for approximately three of the most favorable semiconductor/solvent redox systems. Extended stability and efficiency sensitivity will also be examined in Task 3.

The following accomplishments have been attained in the program: Halide ions influence dark reductions on n-WSe_2 and n-$MoSe_2$ samples with defects or "edges;" treatment with chloride ions can increase the performance of such n-WSe_2 samples for photo-oxidation of thianthrene in acetonitrile.

Promising survey results have been obtained using p-WSe_2 for photoreduction or organic species in acetonitrile. Photoreduction of nitrobenzene can occur with an open circuit voltage of 0.9 V and high concentration of reactant.

Cells constructed using n-WSe_2 for photooxidation of bromide ion or chloride ion acetonitrile electrolytes show efficiencies of 6 to 10%; chloride cells showed apparent stability during chlorine production.

Title: Fabrication of Monocrystalline GaAs Solar Cells Utilizing Sacrificial NaCl Substrates
Contract Number: 9002-5
Directing Organization: Solar Energy Research Institute
Project Engineer: John Benner
Telephone: (303) 231-1396
Contractor: United Technologies Research Ctr.
East Hartford, CT 06108
Principal Investigator: A. J. Shuskus
Telephone: (203) 727-7498
Contract Period of Performance: **From:** 5/15/80 **To:** 5/14/82
Project/Area/Task: Compound Semiconductor/Thin Film GaAs
Contract Funding: FY80 $225,000 FY $ FY $ FY $
Funding Source: SERI

The objective of this project is to establish a process technology for fabrication of low-cost, high efficiency thin film monocrystalline GaAs photovoltaic cells suitable for application in terrestrial or satellite power systems. The goal of the program in the first year is to achieve a cell conversion efficiency of 10 percent or greater employing a GaAs film thickness of less than 10 microns.

Germanium is deposited on the NaCl substrate followed by deposition of molybdenum on the Ge to provide strength after separation from the NaCl. Techniques for separation and handling of the Ge film will be developed. The germanium film will be cleaned and used as a substrate for fabrication of thin single crystal GaAs solar cells.

At present, free standing single crystal films of germanium, 1 cm^2 in area and 10 microns thick, have been prepared. Germanium deposition process parameters have been refined to the extent that films of good quality can be produced consistently. Hall data on free-standing germanium films shows a carrier concentration in the range of 5×10^{15} to 1×10^{16} cm^{-3}, n-type, with a carrier mobility of approximately 900 cm^2/V sec.

Title: Calculate Band Structures of Semiconductors
Contract Number: 1168-1
Directing Organization: Solar Energy Research Institute
Project Engineer: S. Deb
Telephone: (303) 231-1105
Contractor: University of Colorado
Boulder, CO 80309
Principal Investigator: A. Majerfeld
Telephone:
Contract Period of Performance: **From:** 6/1/81 **To:** 5/31/82
Project/Area/Task: Solar Cell R&D
Contract Funding: FY81 $16,139 FY $ FY $ FY $
Funding Source: SERI

The objective of this contract is to write and test a computer program designed to model the electronic properties of semiconductors used in photovoltaic solar energy conversion. This program will include the capabilities to compute:

- the self-consistant band structure of semiconductors such as Si and GaAs from first principles in a mixed-basis representation;
- the total lattice energies of bulk semiconductors in order to predict their mechanical properties;
- the quantum-mechanical forces on atoms in the semiconductors for use in predicting vibrational frequencie and lattice distortions.

Title:	Photoelectric Properties of Amorphous Silicon Deposited by the Pyrolitic Decomposition of Silane		**Contract Number:** 8041-8		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	Ed Sabisky		**Telephone:** (303) 231-1483		
Contractor:	University of Arizona Optical Sciences Center Tucson, AZ 85721				
Principal Investigator:	B. O. Seraphin		**Telephone:** (602) 626-2263		
Contract Period of Performance:	**From:** 9/25/79 **To:** 9/30/80				
Project/Area/Task:	Amorphous Materials				
Contract Funding:	FY79 $28,830	FY80 $24,240	FY $	FY $	
Funding Source:	SERI	SERI			

The photoelectric properties of amorphous silicon films deposited by the pyrolytic decomposition of silane will be studied in order to evaluate the performance of this material in photovoltaic cells. Hydrogenated amorphous silicon used in photovoltaic cells is normally deposited with RF assistance in a glow discharge or is sputtered in a hydrogen-containing atmosphere. Substrate temperatures ranging from 100 to 450°C permit the incorporation of approximately 10% hydrogen into the growing film, in the form of SiH, SiH_2, and SiH_3 complexes.

Working on the photothermal properties of amorphous silicon, we found that this material can be deposited by the pyrolytic decomposition of silane without the assistance of an RF glow discharge. The necessarily higher substrate temperature—typically 600°C—results in a material that: (1) is anneal-stable up to crystallization at 650°C; (2) contains hydrogen in amounts less than 1%, and (3) approaches a fully connected, ideal amorphous state, as evidenced by its optical properties.

Due to the differences in the preparation parameters, this material is unlike other forms of amorphous silicon previously studied for photovoltaic applications. We therefore propose to measure those photoelectric parameters that determine the suitability of our thermally decomposed material for use in solar cells. Using our experience in stabilizing this material against crystallization by doping, we further propose to generate pn-junctions in the growing films and to evaluate their photovoltaic properties.

Title:	Study of Electronic Properties of Defects in Bulk and Surfaces of Semiconductors	**Contract Number:**	1322-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	A. Zunger	**Telephone:**	(303) 231-1172
Contractor:	University of Colorado Campus Box B-19 Boulder, CO 80309		
Principal Investigator:	Dr. James Scott	**Telephone:**	
Contract Period of Performance:	**From:** 9/15/81 **To:** 9/14/82		
Project/Area/Task:	Solar Cell Research and Development		
Contract Funding:	FY81 $25,705 FY $	FY $	FY $
Funding Source:	SERI		

Under this subcontract SERI will add to its program in theoretical solid state physics research a project on the electronic structure of ternary chalcopyrites. This system of relatively new semiconductors (prototype $CuInSe_2$) has been recently discovered to be extremely promising for both conventional photovoltaic solar cell and for stabilizing liquid-solid electrolyte cells. Despite recent successes in making and testing photovoltaic devices made of such materials, little (if anything) is known about their fundamental electronic properties, e.g.,

- Why are they so much stabler than the conventional semiconductors (III-Vs, II-VIs) which do not contain valence d-electrons?
- Which members out of the large class of such materials (30 - 40) are unique? (Only a handful have been tested.)
- What is the effect of cation substitution on the optical and bonding characteristics of these materials?

Title:	Deep Levels in Alloys of III-V Semiconductors	**Contract Number:**	8086-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	S. Deb	**Telephone:**	(303) 231-1105
Contractor:	University of Colorado (Russell Hayes) Boulder, CO 80309		
Principal Investigator:	L. L. Kazmerski	**Telephone:**	(303) 231-1115
Contract Period of Performance:	**From:** 5/1/79 **To:** 4/30/82		
Project/Area/Task:	Solar Cell R&D		

Contract Funding:	FY79 $52,751	FY80 $107,000	FY81 $18,632	FY $
Funding Source:	SERI	SERI	SERI	

A detailed knowledge of deep electronic levels is indispensable for highly efficient multijunction solar cells. In monolithic multijunction cells precisely established combinations are needed of bandgaps, lattice parameters, dopant types and concentrations, as well as layer thicknesses and junction depths. Deep level defects can arise from combinations of these variables, from fabrication techniques, and from certain impurities. The defects impair both the open circuit voltage and the short circuit current, thus the efficiency of the cell.

This study is intended to address one or more of the following areas: (a) refinement of accurate measurement techniques for deep levels; (b) qualitative and quantitative characterization of the deep levels in these compounds, including: equilibrium energy values, association of levels with energy bands, density of levels, and nonequilibrium data derived from transient experiments, such as emission and trapping rates, and energies of activation; and (c) improved preparation procedures for ternary and quaternary alloys of III-V compounds that are candidates for multijunction cells.

When required for construction of apparatus at SERI, the contractor shall provide detailed plans and circuit diagrams for any deep level characterization equipment developed during the period of the contract.

At the beginning of the contract period, sample compositions and diode structures will be determined jointly, depending on the preparation equipment then available to the contractor and to SERI. Samples will be prepared either in the contractor's laboratory or at SERI. Any available preparation method may be used, including liquid phase, vapor phase, and molecular beam epitaxy. Measurements will be carried out in the contractor's laboratory. Copies of measured data as well as their interpretation are to be provided to SERI.

Results of this work will provide data about recombination paths in ternary and quaternary alloys of III-V semiconductors. These data will be used in the design of multijunction solar cells.

Title:	Diagnostics of a Glow Discharge Used to Produce Amorphous Silicon Films			**Contract Number:**	9053-1			
Directing Organization:	Solar Energy Research Institute							
Project Engineer:	H. Mahan			**Telephone:**	(303) 231-1497			
Contractor:	University of Colorado JILA Boulder, CO 80309							
Principal Investigator:	A. Gallagher			**Telephone:**	(303) 492-7841			
Contract Period of Performance:	**From:** 2/15/80 **To:** 4/15/82							
Project/Area/Task:	Advanced Silicon/Amorphous Materials							
Contract Funding:	FY80 $99,278	FY81 $105,303		FY	$		FY	$
Funding Source:	SERI	SERI						

A. Gallagher and J. Scott, at the University of Colorado, are diagnosing the discharges used to produced hydrogenated amorphous silicon films. Radio frequency, dc, and dc-proximity discharges in silane and silane-noble gas mixtures are being studied, primarily by mass spectrometry of the neutral and ion species reaching various surfaces of the discharge. The composition of ion and neutral molecules at the surface are compared to models of the discharge chemistry and field distributions, and some of the critical discharge collision processes are being separately measured. Intrinsic a-Si:H films from different discharges, surfaces, and gas mixtures and purities are compared to each other and to film characteristics reported by other laboratories.

Title:	Semiconductor Properties			**Contract Number:**	9188-1			
Directing Organization:	Solar Energy Research Institute							
Project Engineer:	S. Deb			**Telephone:**	(303) 231-1105			
Contractor:	University of Colorado Boulder, CO 80309							
Principal Investigator:	A. Zunger			**Telephone:**				
Contract Period of Performance:	**From:** 7/1/80 **To:** 9/30/81							
Project/Area/Task:	Solar Cell R&D							
Contract Funding:	FY80 $22,920	FY81 $27,335		FY	$		FY	$
Funding Source:	SERI	SERI						

Under this subcontract, a post-doctoral fellow (Dr. V. Singh) will engage in the following tasks:

1. First principles studies of solid solubilities and ion implantation sites of different dopants in semiconductors. Some work along these lines has been completed and accepted for publication in Physical Review B.

2. Analysis of defect levels in Si and their fundamental electronic properties as a function of (i) impurity electronegativity; (ii) impurity ion size; (iii) number of s versus p electrons in the impurity atom.

3. Study the transition metal impurities in Si and GaP.

Title: Grain Boundary Effects in Photovoltaics
Contract Number: 1097-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Allen Hermann **Telephone:** (303) 231-1311
Contractor: University of Delaware
Institute of Energy Conversion
Mechanical and Aerospace Engineering
117 Evans Hall
Newark, DE 19711
Principal Investigator: J. W. Edington **Telephone:**
Contract Period of Performance: **From:** 1/1/80 **To:** 12/31/81
Project/Area/Task: CdS/Cu_2
Contract Funding: FY80 \$63,348 FY81 \$65,961 FY \$ FY \$
Funding Source: DOE SERI

The purpose of this study is to determine the influence of known grain and low angle boundary structure in CdS and Cu_2S on photovoltaic conversion efficiency.

Well defined grain boundaries were generated in bicrystals and characterized by their influence on minority carrier losses. Electrical properties of the various grain and low angle boundaries were correlated with their defect structure in terms of existing theories. Heterojunction Cu_2S/CdS devices were formed on the bicrystals and the influence of grain boundaries on barrier heights measured.

Title: Zn_3P_2 as an Improved Semiconductor for Photovoltaic Solar Cells
Contract Number: 8062-1
Directing Organization: Solar Energy Research Institute
Project Engineer: Allen Hermann **Telephone:** (303) 231-1311
Contractor: University of Delaware
Institute of Energy Conversion
Wilmington, DE 19808
Principal Investigator: John Meakin **Telephone:** (302) 738-8481
Contract Period of Performance: **From:** 9/1/78 **To:** 2/28/82
Project/Area/Task: Compound Semiconductor/Emerging Matls.
Contract Funding: FY79 \$425,164 FY80 \$284,210 FY81 \$363,394 FY \$
Funding Source: SERI SERI SERI

The objective of this project is to develop high efficiency single crystal and thin-film solar cells based on Zn_3P_2.

The objectives of the FY81 supported effort include: (1) continuation of the development and characterization of n-type Zn_3P_2 bulk material to provide support to the p/n junction device development; (2) development and modelling of Zn_3P_2 p/n junction devices to evaluate the mechanisms which control the junction rectification and limit the conversion efficiency; (3) optimization of thin film Zn_3P_2 deposition by close space vapor transport to obtain thin film areas, 1 cm^2; (4) lowering the resistivity of the thin film p-Zn_3P_2 layers to less than 10 ohm-cm by doping with Ag or other appropriate dopants; (5) development and modelling of transparent Mg/Zn_3P_2 Schottky devices which is compatible with the p/n junction device development; and (6) continue as appropriate the investigation of wide bandgap heterojunction devices.

Device quality Zn_3P_2 thin films have been deposited onto mica and iron substrates by close-space vapor transport. All thin film Mg/Zn_3P_2 devices have exhibited total area efficiencies of approximately 4.3% and show potential to increase the conversion efficiency to 6.0% in the near term.

Title:	Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research			**Contract Number:** 8309-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	Allen Hermann			**Telephone:** (303) 231-1311			
Contractor:	University of Delaware Institute of Energy Conversion Newark, DE 19711						
Principal Investigator:	John D. Meakin			**Telephone:** (302) 995-7155			
Contract Period of Performance:	**From:** 9/1/78 **To:** 2/28/82						
Project/Area/Task:	Compound Semiconductors/Cadmium Sulfide						
Contract Funding:	FY78	$618,941	FY79	$704,856	FY80 $895,551	FY81	$850,000
Funding Source:	DOE		DOE		SERI	SERI	

The objective of this project is to produce thin-film polycrystalline solar cells based on the CdS/Cu_2S junction with energy conversion efficiencies of at least 10% and expected degradation rates of less than 5% in 20 years. Detailed theoretical modeling of the cell was coupled to a broad range of electrical and optical measurements to direct the material and device production leading to progressively more efficient cells.

The program was organized into three tasks: (1) development of improved efficiency of CdS/Cu_2S cells; (2) development of cells based on the $(CdZn)S/Cu_2S$ junction with enhanced open-circuit voltages and higher efficiencies than are possible with CdS/Cu_2S; (3) an experimental and theoretical solar cell analysis effort to provide direction to the other tasks and to achieve a complete understanding of heterojunction photovoltaic devices.

Substituting (CdZn)S for CdS increases the open-circuit voltage. Mixed sulfide films have been grown of uniform and controlled composition. The resistivity can be set at the desired value of 1 to 2 cm without the addition of extrinsic dopants. Cells with efficiencies in excess of 10.2% have been achieved.

The analysis program has achieved a high level of understanding of the heterojunction and has played a key role in the cell improvement program. The junction field in the CdS can be mapped to give estimates of the interface recombination rate.

The stability studies have demonstrated that intrinsic stability can be achieved through the use of lattice-matched rigid substrates and burning out of the few residual defects per cm^2 with the use of a reverse bias current pulse.

Title:	Stability Issues in Cu_2S and $CuInSe_2$ Based on Solar Cells
Contract Number:	8310-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Allen Hermann
Telephone:	(303) 231-1311
Contractor:	University of Delaware Institute of Energy Conversion Wilmington, DE 19808
Principal Investigator:	John Meakin
Telephone:	(302) 995-7155
Contract Period of Performance:	**From:** 7/1/79 **To:** 2/28/82
Project/Area/Task:	CdS/Cu_2S Solar Cells
Contract Funding:	FY79 \$193,764 FY80 \$100,232 FY81 \$4,000 FY \$
Funding Source:	SERI SERI SERI

The Cu_2 and $CuInSe_2$ based cells have achieved an important goal of the National Photovoltaics Program recently by demonstrating conversion efficiencies of near 10%. A major question remaining with regard to these cells is their potential long term stability.

There have been numerous isolated attempts to identify the modes and kinetics of degradation in Cu_2S based cells but the results are usually highly qualitative. The situation with the $CuInSe_2$ based cell is even worse because of the general lack of information about the material and devices. On the other hand there is a highly developed technology for studying and controlling stability in the non-photovoltaic semiconductor industry.

A proposed workshop will attempt to gather many of the experts with relevant experience to discuss the various aspects of the stability issue. It should provide timely information for the CdS program because great emphasis has been recently shifted to this.

Title:	Theory of Thin Film Photovoltaics
Contract Number:	9191-01
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Allen Hermann
Telephone:	(303) 231-1311
Contractor:	University of Delaware Institute of Energy Conversion Newark, DE 19711
Principal Investigator:	Karl W. Boer
Telephone:	(302) 738-8048
Contract Period of Performance:	**From:** 4/15/79 **To:** 8/31/82
Project/Area/Task:	Compound Semiconductors/Cadmium Sulfide
Contract Funding:	FY79 \$52,108 FY80 \$54,500 FY81 \$-0- FY \$
Funding Source:	DOE SERI

Objective: The physics of the photovoltaic effect shall be further developed and applied to thin-film solar cells with the objective to identify important experimental parameters and their optimum range, to prepare means to measure, monitor, and adjust such parameters in order to provide guidance to obtain solar cells with improved cost efficiency. A limited amount of experiments will be used to check key elements of the proposed theory.

Approach: The shape of the current-voltage characteristic of a solar cell depends on the electronic properties of the emitter and junction. These properties change in time for certain Cu_2S/CdS cells leading to hysteresis in the current-voltage characteristic and to cell degradation.

Theoretical analysis of this form of trap-related degradation and comparison of theory with corresponding experiment is proposed. This program will provide guidance to the stability studies on Cu_2S/CdS cells for which the highest efficiency of any thin-film device has been measured (10.2%).

Title:	Improved Efficiency a-Si Solar Cells			**Contract Number:**	9195-1		
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	E. Sabisky			**Telephone:**	(303) 231-1483		
Contractor:	University of Delaware Institute of Energy Conversion One Pike Creek Center Wilmington, DE 19808						
Principal Investigator:	Paul Nielsen			**Telephone:**	(302) 995-7155		
Contract Period of Performance:	**From:** 11/1/79 **To:** 1/31/82						
Project/Area/Task:	Advanced Silicon/Amorphous Materials						
Contract Funding:	FY79	$256,747	FY80	$336,261	FY81	$310,001	FY $
Funding Source:	DOE		SERI		SERI		

The objective of this contract is to develop improved efficiency a-Si solar cell designs and to fabricate improved materials and cells.

Accomplishments:

1. Material Growth:
   - both hydrogenated and fluorinated a-Si films grown
   - high doping efficiency; $\sigma = .05\ (\Omega\text{-cm})^{-1}$ for a n^+a-Si:H and $\sigma = 10\ (\Omega\text{-cm})^{-1}$ for n^+a-Si:F,H
2. Material Properties:
   - reduction of oxygen contamination reduces Egap of a-Si:F:H films to ~ 1.75 eV
   - electron drift mobility measured $\sim 0.2\ cm^2/V\text{-sec}$.
   - Thermoelectric power used to determine bulk defect density at $\sim 10^{16}/cm^3\text{-eV}$ near midgap
3. Device Preparation:
   - p^+in^+ cells made on Mo/glass substrates
   - efficiencies of up to 5% measured
4. Device Design and Analysis:
   - A comprehensive modeling program has been developed to explain the behavior of a-Si cells in terms of density of mid-gap defect states. Analysis shows achievable J_{sc} of 16 mA/cm^2, V_{oc} of 0.9V, and FF of 0.72.

Title:	Physical Models for Thin-Film Polycrystalline Solar Cells Based on Measured Grain Boundary & Electronic Parameter Properties	**Contract Number:**	8275-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	R. W. Hardy	**Telephone:**	(303) 231-1482
Contractor:	University of Florida Electrical Engineering Department Gainesville, FL 32611		
Principal Investigator:	F. A. Lindholm	**Telephone:**	(904) 392-4929
Contract Period of Performance:	**From:** 9/18/78 **To:** 12/14/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		

Contract Funding:	FY78 $130,000	FY79 $122,227	FY81 $199,791	FY $
Funding Source:	DOE	SERI	SERI	

The objectives of the research are: (i) to identify and characterize the basic photovoltaic mechanisms that govern the conversion efficiency of thin-film polycrystalline solar cells; (ii) to experimentally determine the electronic parameters related to these photovoltaic mechanisms; and (iii) to relate these mechanisms and parameters to the conversion efficiency through theoretical physical models developed for engineering design. These models would enable informed design choices to be made to improve cell efficiency.

The approach involves combined theoretical and experimental efforts. The dominant photovoltaic mechanisms are identified from experimental results from solar cells and test structures made from single-crystal and polycrystalline siilicon. Theoretical modelling produces analytic descriptions where possible, but relies on numerical solutions for guidance where necessary.

Grain boundary passivation has been accomplished using two different approaches. The Quasi-Grain-Boundary Free (QGBF) cell uses an etching technique to produce a protective oxide at these etched grain boundaries. Theory predicts heavy losses due to recombination at the intersection of the grain boundary with the space charge region, which can be avoided in the QGBF cell. The second approach is passivation by preferential phosphorus diffusion down grain boundaries. It has been demonstrated that phosphorus can be diffused up to 20 μm down grain boundaries without an increase in dark current.

Quantitative electron beam induced current (EBIC) is being developed as a general tool for material characterization. It is currently being applied to measure recombination velocities at grain boundaries as a function of thermal history.

Title:	$CuInSe_2$			**Contract Number:**	1010-1		
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	S. Deb			**Telephone:**	(303) 231-1105		
Contractor:	University of Maine Orono, Maine 04473						
Principal Investigator:	A. Clark			**Telephone:**	(207) 581-7062		
Contract Period of Performance:	**From:** 11/10/80 **To:** 11/9/81						
Project/Area/Task:	Solar Cell R&D						
Contract Funding:	FY81 $2,100	FY	$	FY	$	FY	$
Funding Source:	SERI						

The program uses electron energy loss spectroscopy (EELS) to characterize copper ternary based photovoltaic devices, mainly $CuInSe_2$. The double-pass cylindrical mirror analyzer is used to study variations in plasmon and interband transition energies due to various preparation conditions. While most of the effort is devoted to material grown by molecular beam epitaxy (MBE), we will be very interested in applying this technique to comparisons of $CuInSe_2$ produced by various investigators engaged in photovoltaic research.

Title:	Photorechargeable Electrochemical Solar Cells Based on Semiconductor Electrodes	**Contract Number:**	9306-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	University of Texas at Austin Austin, TX 78712		
Principal Investigator:	A. J. Bard	**Telephone:**	(512) 471-3761
Contract Period of Performance:	**From:** 8/1/80 **To:** 7/31/82		
Project/Area/Task:	Polycrystalline Thin Films/Photoelectrochemistry		
Contract Funding:	FY80 $59,963	FY81 $120,592	FY $ FY $
Funding Source:	SERI	SERI	

Photorechargeable solar cells consisting of suitable semiconductor and metal electrodes - electrolyte solution combinations containing redox couples having potentials appropriately matched to the semiconductor energy levels will be investigated as the program objective.

Photoelectrochemical redox batteries will be developed using three possible configurations: (a) n-SC/B_{red}/A_{ox}/M, (b) M/B_{red}/A_{ox}/p-SC, and (c) n-SC/B_{red}/A_{ox}/p-SC. Possible systems will be chosen based on the following criteria:

a) Band gap (E_g) of the semiconductor should not be too high ($E_g \leq 2$ eV for maximum efficiency (>10%).
b) Materials stable under illumination in the redox electrolyte.
c) Flat-band potential (V_{fb}) as negative as possible for n-type materials and as positive as possible for p-type materials.
d) Materials with appropriate doping levels (charge carrier densities ~$10^{17}/cm^3$).
e) For "dual photocells", V_{fb} for p-type electrodes should be well positive of V_{fb} for n-type electrodes. The action spectra of n- and p-type electrodes should be well matched.
f) Thin films of polycrystalline materials should be applicable, if possible.

Several characteristics of redox couples are required in photorechargeable PEC cells:

a) Fast heterogeneous kinetics at semiconductor and counter electrodes during change in the light and dark discharge at the inert (current collecting) electrodes.
b) No chemical changes in charged or discharged state on standing or after repeated cycling.
c) Couples can stabilize, or at least do not react with, the electrode surfaces.
d) Highly soluble materials with not too low equivalent weight.
e) Inexpensive, readily available materials
f) Couples with desired redox potential matched to semiconductor energy levels.

Title:	Research on Silicon MIS/ Inversion Layer Cells
Contract Number:	1274-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	R. W. Hardy
Telephone:	(303) 231-1482
Contractor:	University of Washington Joint Center for Graduate Study 100 Sprout Road Richland, WA 99352
Principal Investigator:	L. C. Olsen
Telephone:	(509) 375-3176
Contract Period of Performance:	**From:** 10/1/80 **To:** 9/30/82
Project/Area/Task:	High Efficiency/Polycrystalline Silicon
Contract Funding:	FY80 \$105,000 FY81 \$109,860 FY \$ FY \$
Funding Source:	SERI SERI

The objectives of this work include: (1) understanding of inversion layer formation; (2) MIS/Inversion-Layer Cell fabrication, characterization, and modeling; and (3) stability/degradation studies.

Inversion layers have been modeled in two dimensions to determine the required amount of charge trapped in the oxide for efficient operation. SiO_2 evaporative deposition produces a trapped oxide charge of 4×10^{12} e/cm^2. Only about 1×10^{12} e/cm^2 is required, but electron trapping at the interface cancels some of the trapped positive charge leaving a net charge of 0.4×10^{12} e/cm^2. Hence ways to reduce interface state densities are being sought.

Although present cell design is far from optimum, a 10.1% efficient cell has been confirmed by SERI measurements. Cell characterization indicates that both short circuit current and open circuit voltage decrease with a reduction of trapped oxide charge. Cell modeling shows this to be due to an increase in sheet resistance. No intrinsic degradation has been discovered, but charges from the environment do accumulate on the outer surface of the cell and produce effective degradation. Full cell performance is restored when these outside charges are neutralized. It is speculated that proper encapsulation could solve this problem.

Title:	Investigation of Solar Cells Based on Cu_2O			**Contract Number:** 9190-1			
Directing Organization:	Solar Energy Research Institute						
Project Engineer:	A. Hermann			**Telephone:** (303) 231-1311			
Contractor:	University of Washington Joint Center for Graduate Study Seattle, WA 98195						
Principal Investigator:	Larry C. Olsen			**Telephone:** (509) 943-3176			
Contract Period of Performance:	**From:** 5/1/79 **To:** 5/31/81						
Project/Area/Task:	Emerging Materials						
Contract Funding:	FY79 $161,522	FY80	$106,726	FY	$-0-	FY	$
Funding Source:	SERI	SERI					

The objective of this project is to investigate the photovoltaic properties of solar cells based on Cu_2O, particularly with respect to their potential for low-cost photovoltaic power conversion. Cu_2O is an attractive material for low-cost solar cells since it has a direct bandgap of 2.0 eV and because sheets of large-grain Cu_2O can be grown simply by oxidizing copper.

The focus of the current effort includes: (1) continuation of the development and characterization of controllably doped Cu_2O substrates and evaluation of alternate approaches to thin film growth; (2) development of conductive ZnO films of good optical quality for application in heterojunction devices; (3) development and characterization of greater than 1 cm^2 Cu_2O based Schottky barrier, MIS, or heterojunction solar cell structures with analysis of the mechanisms which control the photocurrent, junction rectification and limit the photovoltaic efficiency.

JCGS has demonstrated an improved short-circuit current of 8.3 mA/cm^2 and an efficiency of 1.76% using a newly developed MIS structure tentatively identified as $Cu/(CuBr)/Cu_2O$. Two current mechanisms have been identified in this structure, one approximated with a J_o equal 10^{-9} A/cm^2 and a diode factor of 1.

In addition, a V_{oc} = 0.42 V has been measured on a ZnO/Cu_2O heterojunction. These improvements may be attributed to an improved substrate cleaning process. Further research is necessary to develop and optimize the Cu_2O substrate preparation and doping process and to fabricate and characterize Cu_2O based solar cell structures in order to confirm their potential for achieving the DOE goals of low cost (less than $300/peak kWe) and high efficiency.

Title:	Research on Silicon MIS/ Inversion Layer Solar Cells	**Contract Number:**	9425-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Rodger Hardy	**Telephone:**	(303) 231-1482
Contractor:	University of Washington Joint Center for Graduate Studies 100 Sprout Road Richland, WA 99352		
Principal Investigator:	L. Olsen	**Telephone:**	FTS 444-7241
Contract Period of Performance:	**From:** 5/1/79 **To:** 9/82		
Project/Area/Task:	Polycrystalline Silicon		
Contract Funding:	FY79 \$161,522 FY80 \$105,000	FY \$	FY \$
Funding Source:	DOE SERI		

The objective of this program is to investigate MIS/Inversion Layer cells theoretically and experimentally. The mechanism of inversion layer formation is to be determined. Cell efficiency, stability, and reproducibility are to be studied with the ultimate aim of optimization. Limitations to photovoltaic performance are to be determined.

The theoretical approach includes calculation of the effect of fixed oxide charge on sheet resistance. Modeling of grid line density, base resistivity, metal work function, etc. shall be carried out in order to evaluate experimental results.

Inversion layer cells will be formed by SiO evaporation. Dependence of fixed oxide charge on processing parameters will be determined by C-V measurements. Optimum grid structures will be determined by trying various grid metals and deposition techniques, including photomasking.

Cell characterization techniques to be employed include measurements for light and dark I-V, spectral response, and C-V. All standard cell parameters, including V_{oc}, I_{sc}, FF, and efficiency will be measured under AM1. Surface concentration profiles obtained by Auger spectroscopy will augment cell stability studies. Stability will be studied under various stresses of illumination, temperature, humidity, and electrical bias. Results will be correlated with models. Encapsulation techniques will be studied.

Title:	Materials for High Efficiency Multijunction Cells	**Contract Number:**	8081-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Cole	**Telephone:**	(303) 231-1841
Contractor:	Varian Associates, Inc. Corporate Solid State Laboratory 611 Hansen Way Palo Alto, CA 94303		
Principal Investigator:	R. L. Bell/M. Ludowise	**Telephone:**	(415) 493-4000
Contract Period of Performance:	**From:** 4/1/79 **To:** 10/31/82		
Project/Area/Task:	High Efficiency Concentrators		

Contract Funding:	FY79 $365,668	FY80 $221,273	FY81 $213,992	FY $
Funding Source:	SERI	SERI	SERI	

The objective of this contract is to develop a materials technology in InGaInAs and AlInAsSb mixed crystal systems which will make available a two-gap monolithic concentrator cell with 28% or higher AM2 conversion efficiency at 500 to 1000 suns.

The proposed multigap cell structures are: (a) GaAs substrate/GaInAs graded region/GaInAs bottom cell/AlGaInAs tunnel junction/AlGaInAs top cell; and (b) InP substrate/AlGaAsSb bottom cell/AlGaAsSb tunnel junction/AlGaAsSb top cell. The most effort to date has been devoted to structure (a); although some attention has been given (b) under a DOE Basic Energy Sciences contract. Substantial progress has been made in setting up the OMVPE system and making it operational. Difficulty in achieving compositional control because of parasitic reactions between some of the reactant gases was overcome by proper selection of source species and growth conditions. Compositional control and uniformity in growth of the GaInAs graded layer is now very good, and it has been shown that the quality of the layer is related to the rate of grading. Problems still exist in controlling the doping in the fabrication of the tunnel junction. Further research needs to be carried out to verify the potential of the various materials systems for fabricating high efficiency cascade solar cells, improving the quality of the low and high bandgap p-n junctions, improving the quality of the intermediate connecting junction, improving control of the doping processes, reducing the amount of strain and defects which degrade the performance of the overall monolithic cascade cell, and demonstrating photovoltaic conversion with a goal of 25 percent efficiency at the end of the contract period.

Title:	Research on High Voltage Cells for Compact Receiver	**Contract Number:**	9010-10
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	L. Cole	**Telephone:**	(303) 231-1841
Contractor:	Varian Associates, Inc. 611 Hansen Way Palo Alto, CA 94303		
Principal Investigator:	R. L. Bell	**Telephone:**	(415) 493-4000 x 2906
Contract Period of Performance:	**From:** 3/1/80 **To:** 3/1/81		
Project/Area/Task:	High Efficiency Concentrators		
Contract Funding:	FY80 $99,795 FY81 $0	FY $	FY $
Funding Source:	SERI		

The study addresses the development of high voltage GaAs/AlGaAs cells for compact concentrator receiver applications. The objective of this program is to fabricate these structures, to evaluate their performance with special emphasis on junction leakage and series resistance effects, and to address techniques for reducing obscuration and obtaining maximum uniformity of performance over the whole cell.

Series sheet resistance appears to be the major problem at this time. By using an emitter contact grid approximately 24% efficiency can be achieved at 400 suns. Computer studies indicate that maximum efficiency occurs at roughly 35 volts per cell assembly.

It should be noted that the metal interconnect technology developed for this program is having a major impact on monolithic cascade cell development.

Title: InP Single Junction Concentrator Cell

Contract Number: 9354-1

Directing Organization: Solar Energy Research Institute

Project Engineer: L. Cole

Telephone: (303) 231-1841

Contractor: Varian Associates, Inc.
Corporate Solid State Laboratory
611 Hansen Way
Palo Alto, CA 94303

Principal Investigator: Peter Borden

Telephone: (415) 493-4000

Contract Period of Performance: **From:** 9/29/80 **To:** 12/28/81

Project/Area/Task: High Efficiency Concentrators

Contract Funding: FY80 $245,698 FY81 $0 FY $ FY $

Funding Source: SERI

The program with Varian Associates addresses the research and development of an InP-based cell in which contacting of both n and p sides of the junction is made from the heat sink side of the cell, thus eliminating the resistance losses and obscuration of front metallization fingers. InP is selected because the low front-surface recombination velocity achievable eliminates the requirement of a higher bandgap "window layer." In addition, using the borosilicate glass/InP sealing technology developed at Varian for photocathode applications allows thin single crystal films of InP to be used.

The objectives of the proposed research effort include the following: (1) evaluate, using test structures, the proper input parameters (e.g., diffusion lengths, recombination velocities, conductivities) for designing and modelling a representative concentrator cell; (2) evaluate various processing techniques for the fabrication of the back-contact cell, such as the glass-sealing operation, groove contacting, and cell/heat sink bonding; (3) fabricate and test a front contact InP concentrator cell to evaluate the high intensity operation of InP junctions and contacts; (4) fabricate and test a back contact InP concentrator cell using the inverted glass-sealed structure; and (5) investigate the advantages of the InP/InGaAsP technology for improving cell performance and easing fabrication problems.

Title:	Material Studies Related to the Cu_2S/(Cd,Zn)S Heterojunction	**Contract Number:**	9075-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Allen Hermann	**Telephone:**	(303) 231-1311
Contractor:	Virginia Polytech Institute & State University Blacksburg, VA 24061		
Principal Investigator:	Larry C. Burton	**Telephone:**	(203) 961-6693
Contract Period of Performance:	**From:** 3/15/80 **To:** 3/14/82		
Project/Area/Task:	CdS/Cu_2S and Cu-ternary		
Contract Funding:	FY80 $58,249	FY81 $57,715	FY $ FY $
Funding Source:	SERI	SERI	

The general objective of this subcontract is to study the electrical and optical properties of Cu_2S/(Cd,Zn)S cells and correlate such properties with compositional analysis. Specific topics being considered are as follows:

- The effects of using (Cd,Zn)S in place of CdS on the rate of formation of Cu_2S and the effectiveness of subsequent heat treatments;
- The possibility of Zn compensation of Cu vacancies to enhance the electrical and optical properties of Cu_2S; and
- The role of Cu in determining the character of the depletion region in CdS and (Cd,Zn)S.

The electrical measurements include the van der Pauw Hall effect of Cu_2S, C-V and photocapacitance, and I-V characteristics at various temperatures. Optical measurements include the absorption spectrum and spectral response of the heterojunction on transparent substrates. Compositional analysis is carried out by AAS and AES/ESCA.

Chemical analysis of cells formed on CdS and (Cd,Zn)S substrate indicate that the rate of Cu_2S formation on CdS is higher than that on (Cd,Zn)S. An anomalous accumulation of Zn at the interface was identified. The excess Zn may result in increased lattice mismatch and in the creation of a conduction band spike at the interface. Both of these effects may account for the low current densities observed in Cu_2S/(Cd,Zn)S cells.

Title:	$CdSiAs_2$ Thin Films For Solar Cell Applications	**Contract Number:**	9143-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	A. Hermann	**Telephone:**	(303) 231-1311
Contractor:	Virginia Poly. Inst. & State Univ. Blacksburg, VA 24061		
Principal Investigator:	L. C. Burton	**Telephone:**	(703) 961-6693
Contract Period of Performance:	**From:** 4/9/79 **To:** 7/31/81		
Project/Area/Task:	Emerging Materials		
Contract Funding:	FY79 $140,259 FY80 $135,851 FY $-0- FY $		
Funding Source:	DOE SERI		

The program objective is to develop thin film heterojunction solar cells in which the semiconductor materials are cadmium sulfide (CdS) and the chalcopyrite cadmium silicon diarsenide ($CdSiAs_2$).

The approach is based on three major tasks:

- Growth of $CdSiAs_2$ thin films using sputtering and evaporation techniques, and film optimization.
- Film characterization, including composition, x-ray analysis, Hall effect, absorption coefficient and minority carrier diffusion length.
- Solar cell fabrication and measurement, using thin films of $CdSiAs_2$ and CdS.

A new three source ion sputtering machine has recently been made operable. The initial stages of machine characterization have begun using edax and optical methods to evaluate $CdSiAs_2$ thin films on glass. Polycrystalline $CdSiAs_2$ deposition has been confirmed via x-ray diffraction. These films were depositied at 300-400°C.

Title:	Low-Cost Substrates for Polycrystalline Silicon Solar Cells by Electrodeposition Processes		**Contract Number:** 8119-2		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	Joseph B. Milstein		**Telephone:** (303) 231-7299		
Contractor:	Westinghouse Electric Corp. Research and Development Center 1310 Beulah Road Pittsburgh, PA 15235				
Principal Investigator:	William R. Gass		**Telephone:** (412) 256-4048		
Contract Period of Performance:	**From:** 9/29/79 **To:** 11/1/81				
Project/Area/Task:	High Efficiency/Polycrystalline Silicon				
Contract Funding:	FY79 $134,095	FY80 $121,640	FY $-0-	FY $	
Funding Source:	SERI	SERI			

The goal of this program is to identify and develop economical processes for fabricating polycrystalline silicon substrates suitable for photovoltaic applications. Studies have been initiated to evaluate the technical feasibility for producing thin-film polycrystalline silicon sheet on selected substrates by molten salt electrolytic deposition techniques. Acid leaching and electrorefining purification processes currently being developed and tested will permit the utilization of inexpensive silicon feedstocks for the electrodeposition processes.

Feasibility studies by several investigators have confirmed that polycrystalline silicon can be electrolytically deposited on a variety of electrically conductive substrate materials. This program utilizes a binary or ternary molten salt electrolyte consisting of alkali metal fluoride solvents (KF, LiF) into which are dissolved economically acceptable silicon feedstocks such as metallurgical grade (MG) silicon, potassium fluorosilicate (K_2SiF_6), or sand (SiO_2). A voltage applied across the silicon containing molten salt electrolyte deposits elemental polycrystalline silicon on the cathode or negative electrode. Deposition parameters are varied to produce desired silicon crystal size and film thickness. Intentional doping of electrolytes may permit selection of p or n type silicon with desired resistivity.

Polycrystalline silicon has been electrodeposited on several different substrates including silver, tantalum, molybdenum, graphite, and nickel in film thicknesses to 450 μm crystal diameters to 100 μm. Major and trace impurities have been identified and quantized in electrodeposited silicon films and in silicon feedstocks through analytical procedures including optical microscopy, scanning electron microscopy, energy dispersive analysis by x-ray emission spectroscopy, and x-ray diffraction. Acid leaching and electrorefining purification processes have been and are being utilized to reduce undesired impurities one or more orders of magnitude in silicon feedstocks and in silicon deposition electrolytes. Silicon films have been electrically characterized and evaluated for solar cell applications, with the observation of n-type material and low (<1%) efficiency in photovoltaic devices fabricated from n-type silicon electrodeposited on p-type dendritic web silicon.

Title:	Cadmium Sulfide/Copper Sulfide/Heterojunction Cell Research — **Contract Number:** 8143-1
Directing Organization:	Solar Energy Research Institute
Project Engineer:	Allen Hermann — **Telephone:** (303) 231-1311
Contractor:	Westinghouse Electric Corp. Research and Development Center 1310 Beulah Road Pittsburgh, PA 15235
Principal Investigator:	John R. Szedon — **Telephone:** (412) 256-3394
Contract Period of Performance:	**From:** 9/30/77 **To:** 7/10/81
Project/Area/Task:	Compound Semiconductor/Cadmium Sulfide

Contract Funding:	FY74-76 $514,000	FY77 $170,500	FY78 $170,500	FY79 $285,251
Funding Source:	NSF	ERDA	DOE	SERI
Contract Funding:	FY80 $201,849	FY81 $144,612		
Funding Source:	SERI	SERI		

The objective of this program is to conduct research for developing cadmium sulfide/copper sulfide-based thin-film solar cells capable of 10% AMI cell conversion efficiency, with less than 5% degradation in performance over a useful life of 20 years.

To meet the described objective, the Westinghouse Electric Corporation has undertaken a program having four major tasks: (1) to produce thin-film Cu_2S/CdS solar cells of 9% conversion efficiency and document the relevant preparative details for such cells; (2) to assess the prospects of achieving a conversion efficiency of 10% or more in cells fabricated by dry, potentially low-cost processing; (3) to establish a base-line procedure for fabrication of intrinsically stable cells; and (4) to investigate electroplated grids on Cu_2S. For the first task, this basic film preparation, processing methods and cell geometry used by the IEC group have been utilized with efficiencies of about 8% achieved. The electroplated gold grids have given solar cell performance superior to that of the control CdS/Cu_2S cells with evaporated gold grids.

Title:	Investigation of Photovoltaic Mechanisms in Polycrystalline Thin Film Solar Cells	**Contract Number:**	9233-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	Simon Tsuo	**Telephone:**	(303) 231-7682
Contractor:	Westinghouse Elec. Corp Research and Development Center 1310 Beulah Road Pittsburgh, PA 15235		
Principal Investigator:	J. R. Szedon	**Telephone:**	(412) 256-3394
Contract Period of Performance:	**From:** 8/1/78 **To:** 10/31/81		
Project/Area/Task:	High Efficiency/Polycrystalline Silicon		
Contract Funding:	FY78 $341,426 FY79 $223,701	FY80 $187,553	FY $
Funding Source:	ERDA DOE	SERI	

The objective of this program is to clarify fundamental aspects of grain boundary influences on photocurrent collection and opposing current transport in polycrystalline silicon cells. Results of the program should allow better understanding of thin-film polycrystalline silicon solar cells which are being considered as a means of meeting the goals of 10% efficiency or greater at a cost of $0.50 per peak watt (in 1980 dollars).

The approach used is to: (1) model the electrical effects of idealized grain boundaries on solar cell performance; (2) develop techniques of grain boundary characterization using scanned light spot evaluation and lateral sensing methods; and (3) characterize effects of a variety of barrier formation methods and plasma treatments on grain boundary behavior and solar cell performance.

The long standing anomalous behavior of ITO/Si solar cells was resolved. The rectifying direction of the ITO/Si heterojunction has been known to depend on the methods used to deposit the ITO: Spray deposited or vacuum-evaporated ITO yields a rectifying junction on n-Si and an ohmic contact on p-Si, while ion-beam-sputtered ITO gives an ohmic contact on n-Si and a rectifying barrier on p-Si. It was shown that the existence of a damaged surface layer in the junction produced by ion-beam sputtering causes the rectifying direction for the sputter-deposited ITO/Si junction to be different. Irrespective of the material deposited, and irrespective of the doping type, ion-beam sputtering on Si tends to cause the silicon band edges to bend downwards at the surface. It is for this reason that sputter-deposited ITO gives a rectifying junction on p-Si and an ohmic contact on n-Si.

Grain boundary activation by thermal cycling has been further confirmed by laser spot scanning (530 nm wavelength) of cells made on Wacker polycrystalline silicon. Wafers originally adjacent in an ingot (and therefore having identical grain boundaries) had solar cells fabricated on them after one wafer had been heated (2 hr/500°C, 15 min/900°C, 2 hr/500°C) and the other wafer had not. MIS structures were used since they could be fabricated without heating the wafer. Typical photocurrent suppression measured at grain boundaries was less than 15% for unheated wafers and about 40% for heated wafers.

Title:	Test Method Development and Documentation	**Contract Number:**	9353-1
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	P. Longrigg	**Telephone:**	(303) 231-1183
Contractor:	Wyle Laboratories Huntsville, AL 35804		
Principal Investigator:	S. Patrick	**Telephone:**	(205) 837-4411
Contract Period of Performance:	**From:** 10/1/80 **To:** 11/1/81		
Project/Area/Task:	PC/TM		
Contract Funding:	FY81 $141,162 FY $	FY $	FY $
Funding Source:	SERI		

This contract was directed at documentation of existing PV test methods in conformance with the SERI format, which closely approximates those in use in the consensus standards organizations, and at development of required test methods to support PV systems Interim Performance Criteria. This work included the addition of accuracy and precision statements for each test method. Specific test method developments include:

- Residential PV inverter performance
- Intermediate load, 3 phase inverter performance
- Stand-alone PV inverter, with battery storage, performance
- Storage battery tests for capacity, efficiency, rapid gas charging
- Review and evaluation of NOCT test method using computer modelling techniques for thermal profiling.

Title:	Structural and Electronic Studies of Defects in Hydrogenated Amorphous Silicon		**Contract Number:** 9079-1		
Directing Organization:	Solar Energy Research Institute				
Project Engineer:	H. Mahan		**Telephone:** (303) 231-1497		
Contractor:	Xerox Corporation Palo Alto Research Center Palo Alto, CA 94304				
Principal Investigator:	R. Street		**Telephone:** (415) 494-4120		
Contract Period of Performance:	**From:** 2/1/79 **To:** 5/1/82				
Project/Area/Task:	Advanced Silicon/Amorphous Materials				
Contract Funding:	FY79 $91,000	FY80 $176,043	FY81 $187,641	$	FY$
Funding Source:	DOE	SERI	SERI		

This program is aimed at a basic understanding of the structure and electrical properties of a-Si:H. Particular emphasis is placed on those properties that impact device performance. One aspect of the structural studies concerns the properties of Schottky barriers. We have found that palladium and platinum on a-Si:H form crystalline silicides, and their structure has been investigated by Raman scattering. Au forms a non-crystalline Au-Si phase. The formation of the silicides improves electrical properties of the Schottky electrical properties of the Schottky barriers, and the diodes are found to be nearly ideal. The studies of Schottky barriers will be extended to include other metals. We are also studying the hydrogen bonding structure by nuclear magnetic resonance in order to gain information about the microstructure of a-Si:H.

The studies of electronic properties are aimed at understanding the properties of defect and band tail states, in particular their effect on the recombination of photoexcited carriers. The techniques used are luminescence, electron spin resonance, and deep level transient spectroscopy (DLTS). We are investigating how the spin orientation of paramagnetic centers affects the recombination rate. DLTS is used to investigate the energy spectrum of localized states.

Title:	High Efficiency Thin Film Cadmium Chalcogenide Photo-electrochemical Cell with In Situ Storage	**Contract Number:**	9010-11
Directing Organization:	Solar Energy Research Institute		
Project Engineer:	William Wallace	**Telephone:**	(303) 231-1380
Contractor:	Yeda Research & Development The Weizmann Institute of Science Rehovot, Israel		
Principal Investigator:	Joost Manassen	**Telephone:**	
Contract Period of Performance:	**From:** 10/1/80 **To:** 9/31/81		
Project/Area/Task:	Polycrystalline Thin Film/Photoelectrochemistry		
Contract Funding:	FY80 $97,120	FY81 $61,580	FY $ FY $
Funding Source:	SERI	SERI	

The objectives of the program are to construct and characterize experimental three electrode photo-electrochemical storage cells incorporating n-$CdSe_xTe_{1-x}$ photoanodes, a Sn/SnS storage electrode, a cobalt sulfide or copper sulfide counterelectrode and a sulfide/polysulfide electrolyte.

A technical concept for a three electrode photoelectrochemical storage cell has been developed, and a cell constructed. This cell in principle is a module of a larger unit comprising many such cells in series.

The main drawback still is the peculiar chemistry of the tin/polysulfide system. Tin disulfide has been prepared and the potential behavior of a tin electrode in a tin sulfide solution will be studied more quantitatively.

Photovoltaics Technology Development and Applications

The Photovoltaic Technology Development and Applications program is managed by the Jet Propulsion Laboratory under an agreement between the Department of Energy and the National Aeronautics and Space Administration (NASA).

Field organizations with implementing project responsibility include:

- Sandia Laboratories
- Jet Propulsion Laboratory — Photvoltaics Technology Development and Applications Lead Center
- Jet Propulsion Laboratory — Flat-Plate Solar Array Project
- Massachusetts Institute of Technology/Lincoln Laboratory
- NASA/Lewis Research Center.

Some activities have been subcontracted by the Department of Energy's Albuquerque Operations Office. Active contracts are organized alphabetically by contractor according to the institution with contract management responsibility.

Sandia National Laboratories

Title: 75 kW Array Simulator **Contract Number:** 46-0150
Directing Organization: Sandia National Laboratories
Project Engineer: C. M. Coats **Telephone:** (505) 844-5206
Contractor: Abacus Controls
P.O. Box 893
Somerville, NJ 08876
Principal Investigator: George O'Sullivan **Telephone:** (201) 526-6010
Contract Period of Performance: **From:** 01-24-80 **To:** 07-15-81
Project/Area/Task: Power Conditioning and Control/PCS Test and Engineering Evaluation
Contract Funding: FY80 $66,400 FY81 $32,400 FY $ FY $
Cumulative Funding To Date: $98,800

Contract objectives are to design and build a 75-kW PV solar array simulator. Unit has been completed and is in factory test at Abacus.

Title: Parabolic Trough Development **Contract Number:** 13-9493
Directing Organization: Sandia National Laboratories
Project Engineer: E. C. Boes **Telephone:** (505) 844-5634
Contractor: Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042
Principal Investigator: D. Rafinejad **Telephone:** (415) 964-3200
Contract Period of Performance: **From:** 11-09-79 **To:** 11-30-81
Project/Area/Task: PV Concentrator Project
Contract Funding: FY80 $218,700 FY81 $16,500 FY $ FY $
Cumulative Funding To Date: $235,200

Contract objectives are to develop an improved receiver design for Acurex's PV trough; investigate different ways of using silvered glass mirrors on their trough; and investigate analytically the effects of a split-trough design.

All technical efforts are complete. Final report preparation is awaiting Sandia approval of the draft.

Title:	Low Cost PV Concentrator Module Development	**Contract Number:**	62-7216
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	Acurex Corporation 485 Clyde Avenue Mountain View, CA 94042		
Principal Investigator:	D. Rafinejad	**Telephone:**	(415) 964-3200
Contract Period of Performance:	**From:** 03-03-81 **To:** 04-30-82		
Project/Area/Task:	Concentrator Concept Development		
Contract Funding:	FY81 $390,840 FY $	FY $	FY $
Cumulative Funding To Date:	$390,840		

Contract objective is to advance the maturity of the linear lens PV concentrator module through second generation development. In particular, a PV module is to be developed to exhibit an evaluation in efficiency, cost effectiveness, durability, reliability, and mass production. Solar cells from two manufacturers to be evaluated. Successful preliminary design review was held in June. Final design is essentially complete. Final design review to be held in October. Program is on schedule.

Title:	Off Farm Agricultural Applications	**Contract Number:**	62-6590
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	Advanced Technology, Inc. 7923 Jones Branch Drive McLean, VA 22102		
Principal Investigator:	W. F. Adolfson	**Telephone:**	(704) 442-4647
Contract Period of Performance:	**From:** 10-14-81 **To:** 12-14-81		
Project/Area/Task:	Sandia AOP Applications Analysis		
Contract Funding:	FY80 $242,000 FY $	FY $	FY $
Cumulative Funding To Date:	$242,000		

Contract objectives are to:

1. Develop data base of energy consumption patterns in off-farm agricultural sector for use in subsequent tasks.
2. Identify those applications which can most effectively substitute PV for conventional power systems.
3. Develop conceptual PV designs for applications identified.
4. Estimate performance & life cycle costs for proposed conceptual designs.
5. Recommend appropriate applications for near-term experimental/demonstration projects.

Program is as follows:

1. Data base prepared and delivered.
2. Appropriate applications identified.
3. Conceptual designs underway.
4. Life cycle cost analysis underway.

Title: Residential Design Sensitivity Analysis
Contract Number: 62-6697
Directing Organization: Sandia National Laboratories
Project Engineer: Gary J. Jones
Telephone: (505) 844-2433
Contractor: AIA Research Corporation
1735 New York Avenue, NW
Washington, DC 20006
Principal Investigator: George Royal
Telephone: (202) 626-7544
Contract Period of Performance: **From:** 07-28-80 **To:** 09-15-81
Project/Area/Task: Conceptual Design & Optimization
Contract Funding: FY80 $49,700 FY $ FY $ FY $
Cumulative Funding To Date: $49,700

Contract objectives are to analyze current designs, investigate the effects of "marketable" passive solar features, and determine the range of space conditioning loads expected.

- Task I - Critique of the assumptions used in base design and analysis of the 1986 prototype residences.
- Task II - Modification of prototype residences.
- Task III - Simulation of the performance of these modified residences and evaluation of the results.

The final report has been received and is undergoing final review. It will be published as SAND81-7045.

Title: Silicon Cell Development
Contract Number: 46-2042A
Directing Organization: Sandia National Laboratories
Project Engineer: H. T. Weaver
Telephone: (505) 844-8979
Contractor: Applied Solar Energy Corporation
P.O. Box 1212
City of Industry, CA 91749
Principal Investigator: Ken Ling
Telephone: (213) 968-6581
Contract Period of Performance: **From:** 07-01-80 **To:** 01-01-81
Project/Area/Task: Silicon Cells
Contract Funding: FY80 $45,600 FY $ FY $ FY $
Cumulative Funding To Date: $45,600

Contract objectives are to fabricate and place silicon cells on received assembly unit. These mounted cells will be used in Sandia Baseline Modules and for cell assembly evaluation.

Effort will be completed in the second quarter of FY 1982 and assemblies received.

Title:	Solar Cell Development			**Contract Number:** 49-2670			
Directing Organization:	Sandia National Laboratories						
Project Engineer:	H. T. Weaver			**Telephone:** (505) 844-8979			
Contractor:	Applied Solar Energy Corporation P.O. Box 1212 City of Industry, CA 91749						
Principal Investigator:	Ken Ling			**Telephone:** (213) 968-6581			
Contract Period of Performance:	**From:** 04-01-80 **To:** 04-01-81						
Project/Area/Task:	Silicon Cells						
Contract Funding:	FY80 $299,300	FY	$	FY	$	FY	$
Cumulative Funding To Date:	$299,300						

Contract objectives is to develop method for fabricating high efficiency solar cells. ASEC will make both N on P and P on N type cells and compare them. An efficiency goal is 20% at 50X.

Contract is complete. Twenty-five cells have been received, and the final report received.

Title:	Design & Fabricate a PV Actively Cooled Linear Receiver Assembly			**Contract Number:** 62-9828			
Directing Organization:	Sandia National Laboratories						
Project Engineer:	L. C. Beavis			**Telephone:** (505) 844-2231			
Contractor:	Applied Solar Energy Corporation 15251 E. Don Julian Rd. City of Industry, CA 91746						
Principal Investigator:	Steve Olah			**Telephone:** (213) 968-6581			
Contract Period of Performance:	**From:** 09-30-80 **To:** 12-31-81						
Project/Area/Task:	Concentrator Concept Development						
Contract Funding:	FY81 $45,000	FY	$	FY	$	FY	$
Cumulative Funding To Date:	$45,000						

Contract objective is to design and fabricate linear receivers for SNL parabolic trough. One receiver was returned for rework due to electrical and encapsulant failure (July 1981). It was repaired and shipped to SNL on October 9, 1981. Contract was extended, no increase in cost, for shipping of hardware needing repair.

Title:	Cell Receiver Testing	**Contract Number:**	40-1356
Directing Organization:	Sandia National Laboratories		
Project Engineer:	R. D. Nasby	**Telephone:**	(505) 844-6137
Contractor:	Arizona State University Mechanical Engr. Dept. Tempe, AZ 85281		
Principal Investigator:	Dr. C. Backus	**Telephone:**	(602) 965-3857
Contract Period of Performance:	**From:** 01-01-80 **To:** 12-31-80		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY81 $156,833 FY $	FY $	FY $
Cumulative Funding To Date:	$156,833		

Contract objectives include test and evaluation of concentrator cells, receivers, and complete modules. Also included is the development of standard test methods for the above. The contract is in progress and replaces #49-1510.

Title:	Concentrator Technology Studies	**Contract Number:**	49-1510
Directing Organization:	Sandia National Laboratories		
Project Engineer:	R. D. Nasby	**Telephone:**	(505) 844-6137
Contractor:	Arizona State University Mechanical Engr. Dept. Tempe, AZ 85281		
Principal Investigator:	Dr. C. Backus	**Telephone:**	(602) 965-3857
Contract Period of Performance:	**From:** 01-01-80 **To:** 12-31-80		
Project/Area/Task:	Array Design & Fabrication		
Contract Funding:	FY80 $150,000 FY $	FY $	FY $
Cumulative Funding To Date:	$150,000		

Contract objectives include test and evaluation of concentrator cells, receivers, and complete modules. Also included is the development of standard test methods for the above.

Contract has been completed; new contract #40-1356 is in progress.

Title:	Fabricate and Deliver an Azimuth Tracking Array	**Contract Number:**	62-6536
Directing Organization:	Sandia National Laboratories		
Project Engineer:	E. C. Boes	**Telephone:**	(505) 844-5634
Contractor:	University of Arizona Water Resources Center Tucson, AZ 85721		
Principal Investigator:	C. B. Cluff	**Telephone:**	(602) 626-1808
Contract Period of Performance:	**From:** 08-01-80 **To:** 12-31-81		
Project/Area/Task:	Concentrator Module Development		
Contract Funding:	FY80 $37,700 FY $	FY $	FY $
Cumulative Funding To Date:	$37,700		

Contract objectives are to fabricate and test a low-concentration (5-10X) array that uses flat-plate modules and azimuth tracking via flotation on a shallow pond.

The array is undergoing testing and modifications at University of Arizona. Initial data indicate that performance is about 2 kW compared with 4 kW expected. The floating structure works adequately. Discussions of possible modifications are underway.

Title:	Intermediate Sector Retrofit Study	**Contract Number:**	62-1259
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	Battelle Columbus Laboratories 505 King Avenue Columbus, OH 43201		
Principal Investigator:	G. T. Noel	**Telephone:**	(614) 424-7481
Contract Period of Performance:	**From:** 08-12-80 **To:** 12-12-81		
Project/Area/Task:	Sandia AOP Applications Analysis		
Contract Funding:	FY80 $209,600 FY $	FY $	FY $
Cumulative Funding To Date:	$209,600		

Contract objectives are to:
1. Review existing literature and characterize existing intermediate structures in NE, SE, and SW U.S.
2. Select representative intermediate sector structures and appropriate PV systems for retrofitting to these structures.
3. Propose detailed retrofitting schemes, estimate resultant costs, and estimate potential markets.
4. Recommend development of special or unique hardware which might be needed for widespread intermediate PV retrofits.

Progress is as follows:
1. Research methodology approved.
2. Representative structures and PV systems chosen.
3. Retrofitting schemes under development.

Title: Reliability Methodology Development
Contract Number: 62-8278
Directing Organization: Sandia National Laboratories
Project Engineer: M. Rios
Telephone: (505) 844-7812
Contractor: Battelle Columbus Laboratories
505 King Avenue
Columbus, OH 43201
Principal Investigator: Larry Stember
Telephone: (614) 424-6424
Contract Period of Performance: **From:** 01-01-81 **To:** 12-31-81
Project/Area/Task: Array Subsystems
Contract Funding: FY81 $217,000 FY $ FY $ FY $
Cumulative Funding To Date: $217,000

The objective of this contract is to develop a methodology to help ensure the development of reliable photovoltaic power systems and to assist in the reliability tradeoffs that will lead to minimum live-cycle costs. Thus the contract is intended to result in a methodology whereby the operating and maintenance life-cycle costs of a PV system may be estimated through the use of appropriate models and incorporated into the total system life-cycle costs.

A PV Systems Reliability Analysis Methodology has been developed such that life-cycle maintenance costs can be computed and incorporated into system life-cycle costs. The methodology can utilize either a Markov chain model of system availability or computer simulation. The methodology is being applied to three real world PV systems (based on PRDA-35, 38 designs) for a range of economic parameters. The three PV systems are for intermediate applications and include a flat-plate system, a PV-T system, and a passively cooled concentrating system. Technical work is expected to be completed by January 30, 1982.

Title: PV Array Field Optimization and Modularity Study
Contract Number: 62-9187
Directing Organization: Sandia National Laboratories
Project Engineer: H. N. Post
Telephone: (505) 844-2154
Contractor: Battelle Columbus Laboratories
505 King Avenue
Columbus, OH 43201
Principal Investigator: D. C. Carmichael
Telephone: (614) 424-6582
Contract Period of Performance: **From:** 12-29-80 **To:** 11-28-81
Project/Area/Task: Array Subsystems
Contract Funding: FY81 $498,100 FY $ FY $ FY $
Cumulative Funding To Date: $498,100

The overall objective is to reduce the cost of medium-sized PV array fields by reducing the cost of structural and electrical subsystem designs, their components, and their installation. Subsystems to be investigated include the support structure, foundation, site preparations, field wiring, grounding, and lightning protection. The low-cost designs to be developed are to be for flat-panel, ground-mounted arrays and are to be applicable for near-term implementation to reduce balance-of-system costs. Contract effort is on schedule and progressing.

Title:	PV Concentrator Array Field Optimization and Modularity Study	**Contract Number:**	68-1517
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. N. Post	**Telephone:**	(505) 844-2154
Contractor:	Battelle Columbus Laboratories 505 King Avenue Columbus, OH 43201		
Principal Investigator:	D. C. Carmichael	**Telephone:**	(614) 424-6582
Contract Period of Performance:	**From:** 08-15-81 **To:** 04-15-82		
Project/Area/Task:	Array Subsystem Development		
Contract Funding:	FY81 $197,500 FY $	FY $	FY $
Cumulative Funding To Date:	$197,500		

The overall objective is to develop modularized PV concentrator array field building block designs, including sizing, which minimizes the field installation and wiring costs for two PV concentrator array designs utilizing passive cooling and two-axis tracking. The building block designs will be suitable for use alone or in multiples to construct low-cost medium and large-sized array fields. Work is underway.

Title:	Bonding System Design for Cell Substrates	**Contract Number:**	61-0024
Directing Organization:	Sandia National Laboratories		
Project Engineer:	L. C. Beavis	**Telephone:**	(505) 844-2231
Contractor:	BDM Corporation 1801 Randolph Road, SE Albuquerque, NM 87106		
Principal Investigator:	B. Schwinkendord	**Telephone:**	(505) 848-5318
Contract Period of Performance:	**From:** 08-06-81 **To:** 11-30-82		
Project/Area/Task:	Manufacturing Development		
Contract Funding:	FY81 $144,900 FY $	FY $	FY $
Cumulative Funding To Date:	$144,900		

Contract objective is to develop new bonding (cell laydown) system with the emphasis on filled organic materials.

The contract is on schedule as of January 1, 1982. First thermal conductivity samples delivered for measurement by Div. 5824. M. Moss of 5824 has asked that samples for thermal conductivity measurements be changed (December 1981). This request has been accepted although it will cause some minor delays (due to fabrication of specimen).

Task I, II report was received December 15, 1981.

Title: Determination of Detailed Residential Load Profile
Contract Number: 62-3977
Directing Organization: Sandia National Laboratories
Project Engineer: J. L. Jackson
Telephone: (505) 844-7825
Contractor: BDM Corporation
1809 Randolph, SE
Albuquerque, NM 87106
Principal Investigator: G. C. Collaras
Telephone: (505) 848-5000
Contract Period of Performance: From: 10-14-80 To: 02-28-82
Project/Area/Task: Sandia AOP Applications Analysis
Contract Funding: FY81 $255,000 FY $ FY $ FY $
Cumulative Funding To Date: $255,000

The following are contract objectives:

1. A comprehensive survey of utilities and related sources to determine availability of real-time instantaneous and time averaged load data for typical residences.
2. A direct measurement program in the three regions (NE, SE, SW CONUS) to supplement data gaps.
3. Development of a statistical load model to predict the frequency and intensity of instantaneous spikes.
4. Verify model and the calculations of the annual load demand met by a PV system.

Progress is as follows:

1. Comprehensive survey completed.
2. Summer direct measurement completed. Winter program to begin December 1, 1981.
3. Statistical load model development underway.

Title: Subsystem Optimization and Design Tradeoff Study
Contract Number: 46-0042
Directing Organization: Sandia National Laboratories
Project Engineer: Gary J. Jones
Telephone: (505) 844-2433
Contractor: Bechtel National, Inc.
P.O. Box 3965
San Francisco, CA 94119
Principal Investigator: W. J. Stolte
Telephone: (415) 768-5834
Contract Period of Performance: From: 04-01-80 To: 12-31-81
Project/Area/Task: Engineering Support
Contract Funding: FY80 $286,600 FY81 $61,400 FY $ FY $
Cumulative Funding To Date: $348,000

The purpose of this contract is to address certain topics regarding engineering design options and subsystem specification for large intermediate and central station applications.

- Task I - Field design and wiring layout optimization for large ground-mounted arrays.
- Task II - Power conditioning type and selection for large application and subfield size selection based on PCU cost and array voltage requirement.
- Task III - Support structure design and installation automation and analysis of roof-mounted structures.

Additional effort was initiated on power conditioning type tradeoffs (line versus self-commutated) in FY1981. These results will be issued as a separate report. The main report will be SAND81-7013.

Title:	Integrated Structure Designs for PV Arrays	**Contract Number:**	62-9877
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. N. Post	**Telephone:**	(505) 844-2154
Contractor:	Bechtel Group, Inc. P.O. Box 3965 San Francisco, CA 94119		
Principal Investigator:	H. A. Franklin	**Telephone:**	(415) 768-8778
Contract Period of Performance:	**From:** 12-12-80 **To:** 02-12-82		
Project/Area/Task:	Array Subsystem Development		
Contract Funding:	FY81 $428,400 FY $	FY $	FY $
Cumulative Funding To Date:	$428,400		

The objective of this work is to develop low-cost, integrated structure designs for photovoltaic arrays. The work includes an examination of totally integrated flat-plate panel/low-cost support structure design with emphasis on realistic wind loading criteria, dynamic response characteristics, and detailed costing. An array field of prototype structures will be installed at Sandia's test facility to verify the integrated structure design and costs as well as provide actual experience in the fabrication, mechanical integration, and installation of the support system.

The structure design activity is near completion. Wind tunnel testing has been completed. Draft construction specifications for the prototype structures have been completed.

Title:	Silicon Concentrator Cell Development	**Contract Number:**	46-2122
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. T. Weaver	**Telephone:**	(505) 844-8979
Contractor:	Boeing P.O. Box 3999 M/S 88-05 Seattle, WA 98124		
Principal Investigator:	Betty Zimmerman	**Telephone:**	(206) 773-2298
Contract Period of Performance:	**From:** 02-01-80 **To:** 03-30-81		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY80 $144,100 FY $	FY $	FY $
Cumulative Funding To Date:	$144,100		

Contract objective is to develop methods for plating narrow metal lines on silicon concentrator solar cells. Primary areas are the use of photoresist to define lines during plating and the use of pulse plating techniques.

Final report was approved, and has been submitted for publication.

Title:	Photovoltaics & Electric Utilities	**Contract Number:**	49-5571
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	Brookhaven National Laboratories Upton, NY 11973		
Principal Investigator:	R. Bryant	**Telephone:**	FTS 666-2800
Contract Period of Performance:	**From:** 04-01-80 **To:** 11-30-81		
Project/Area/Task:	Applications Analysis		
Contract Funding:	FY80 $143,000 FY $	FY $	FY $
Cumulative Funding To Date:	$143,000		

Case studies to be conducted for three U.S. electric utilities to determine the economics of photovoltaics for the utilities, the homeowner, and society as a whole. The three utilities will be chosen to form a representative cross-section of utilities nationwide.

Draft final report has been approved. Final report due October 15, 1981.

Title:	Stamped Sheet Metal Trough Development	**Contract Number:**	13-8721
Directing Organization:	Sandia National Laboratories		
Project Engineer:	R. L. Champion	**Telephone:**	(505) 844-8643
Contractor:	The Budd Company Technical Center 375 Commercial Drive Port Washington, PA 19034		
Principal Investigator:	A. W. Biester	**Telephone:**	(215) 643-2950
Contract Period of Performance:	**From:** 09-01-79 **To:** 01-31-82		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY $ FY $	FY $	FY $
Cumulative Funding To Date:	$235,300		

Contract objectives are to investigate fabrication of stamped sheet metal parabolic trough reflector panels and determine tooling requirements and accuracy obtained with sheet metal panels produced quasi-production tooling and high volume production techniques.

Contract deliverables all delivered except for final report. Contract extended to January 31, 1982, to allow time for completion of draft of final report, submission for approval, and publishing.

Title: Automated Installation Methods for PV Arrays — **Contract Number:** 74-0751
Directing Organization: Sandia National Laboratories
Project Engineer: H. N. Post — **Telephone:** (505) 844-2154
Contractor: Burt Hill Kosar Rittelmann Assoc.
400 Morgan Center
Butler, PA 16001
Principal Investigator: J. R. Oster — **Telephone:** (412) 285-4761
Contract Period of Performance: From: 02-09-81 To: 01-12-82
Project/Area/Task: Array Subsystem Development
Contract Funding: FY81 $296,700 FY $ FY $ FY $
Cumulative Funding To Date: $296,700

The objectives of this work are to identify and evaluate automated installation methods for large, ground-mounted PV array fields. Both flat panel and concentrator PV arrays are considered. The cost effectiveness of automated and innovative installation methods will be evaluated through detailed installation scenarios for a variety of array field designs.

Automated installation methods have been identified and are currently being evaluated through rank ordering for five flat panel structural subsystems and two concentrator arrays. Detailed installation scenarios for each array field option are in progress.

Title: Thin Film Barriers — **Contract Number:** 68-0429
Directing Organization: Sandia National Laboratories
Project Engineer: Len Beavis — **Telephone:** (505) 844-2231
Contractor: California Institute of Tech.
Attn: David Morrisroe
1201 E. California Blvd.
Pasadena, CA 91125
Principal Investigator: Dr. M. A. Nicolet — **Telephone:** (213) 356-6357
Contract Period of Performance: From: 09-16-81 To: 09-30-82
Project/Area/Task: Silicon Cells
Contract Funding: FY79 $245,600 FY $ FY $ FY $
Cumulative Funding To Date: $245,600

Contract objectives are to develop diffusion barriers for metallizations used in Si solar concentrator cells. TiN_2 primary material under consideration; to design a metallization-diffusion barrier GaAlAs and silicon, using TiN_2.

Work is in process under extension. Presently TiN_2 thickness is limited to about 0.3 μm because of enormous internal stresses in the TiN_2 film. Means of measuring and controlling internal stresses are being studied so a thicker film can be developed which will act as metallization in addition to diffusion barrier. 0.2 μm TiN_2 barrier is capable of eliminating diffusion of overlayers of Cu or Ag into Si for at least 10 min. at 600°C.

Title:	Solar Cell Research	**Contract Number:**	49-2603
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. T. Weaver	**Telephone:**	(505) 844-8979
Contractor:	University of California Campus Research Office M11 Wheeler Hall Berkeley, CA 94720		
Principal Investigator:	Dick White	**Telephone:**	(415) 642-0540
Contract Period of Performance:	**From:** 05-01-80 **To:** 05-01-81		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY80 $63,500 FY $	FY $	FY $
Cumulative Funding To Date:	$63,500		

Contract objective is to develop a novel cell for application in high concentration systems. Final report is due the first quarter of FY 1982.

Title:	Investigation of Load Management Strategies for Residential PV Systems	**Contract Number:**	62-9162
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	Clemson University Department of Elec. Engr. & Comp. Engr. Clemson, SC 29631		
Principal Investigator:	J. Lathrop	**Telephone:**	FTS 672-3378
Contract Period of Performance:	**From:** 09-15-80 **To:** 01-01-82		
Project/Area/Task:	Sandia AOP Power; Conditioning & Control		
Contract Funding:	FY80 $50,000 FY $	FY $	FY $
Cumulative Funding To Date:	$50,000		

Contract objective is to develop a computer model to simulate a utility-connected residential PV system with battery storage and to use this model in the development of various load management studies.

Computer model has been developed and is being modified to permit faster run times. Model output is being compared with existing empirical data. Work is beginning on final report due second quarter of FY 1982.

Title:	Passive Cooling Studies		**Contract Number:** 62-1271		
Directing Organization:	Sandia National Laboratories				
Project Engineer:	M. W. Edenburn		**Telephone:** (505) 844-4003		
Contractor:	Energy Engineering, Inc. 1704 Stanford, NE Albuquerque, NM 87106				
Principal Investigator:	Tom Feldman		**Telephone:** (505) 277-6313		
Contract Period of Performance:	**From:** 04-01-80 **To:** 05-31-81				
Project/Area/Task:	Concentrator Concept Development				
Contract Funding:	FY80 $25,100	FY81 $12,000	FY $	FY $	
Cumulative Funding To Date:	$37,100				

Contract objectives are to fabricate and test a heat exchanger for a linear PV array. A revised draft copy of the report has been submitted for review.

Title:	Linear Fresnel Lens Development		**Contract Number:** 13-2359		
Directing Organization:	Sandia National Laboratories				
Project Engineer:	C. B. Stillwell		**Telephone:** (505) 844-2130		
Contractor:	E-Systems, Inc. Energy Technology Center P.O. Box 22618 Dallas, TX 75266				
Principal Investigator:	M. O'Neill		**Telephone:** (214) 272-0515		
Contract Period of Performance:	**From:** 01-03-79 **To:** 09-30-81				
Project/Area/Task:	Concentrator Concept Development				
Contract Funding:	FY79 $213,900	FY $	FY $	FY $	
Cumulative Funding To Date:	$213,900				

Contract objective is to develop a low-cost linear Fresnel lens for photovoltaic concentrators using the extrusion/embossed process.

Optical quality of lenses made by this process to date is not acceptable. Test runs to explore ability of process to reproduce various facet widths showed 0.075 in. wide facets reproduced significantly better than current 0.025 in. wide facet design. It is planned to extend contract to remake lens master embossing roller with 0.075 in. wide facets and to make new extrusion/embossing runs for evaluation.

Title: Linear Fresnel Lens Array Development — **Contract Number:** 46-5791
Directing Organization: Sandia National Laboratories
Project Engineer: M. Rios — **Telephone:** (505) 844-7812
Contractor: E-Systems
P.O. Box 6118
Dallas, TX 75222
Principal Investigator: Mark O'Neill — **Telephone:** (214) 272-0515 ext 3830
Contract Period of Performance: From: 01-31-80 To: 01-31-81
Project/Area/Task: Array Design and Fabrication
Contract Funding: FY80 $492,098 FY $ FY $ FY $
Cumulative Funding To Date: $492,098

Contract objectives include redesign E-Systems' linear Fresnel lens photovoltaic concentrator array for higher performance and lower cost, build and test prototype collectors; and build, test, and deliver a full scale array.

No problems are currently anticipated. Program on schedule consistent with last contract revision.

Title: Advanced Silicon Concentrator Cell Development — **Contract Number:** 28-1161
Directing Organization: Sandia National Laboratories
Project Engineer: R. D. Nasby — **Telephone:** (505) 844-6137
Contractor: University of Florida
Dept. of Electrical Engineering
Gainesville, FL 32611
Principal Investigator: Jerry G. Fossum — **Telephone:** (904) 392-4921
Contract Period of Performance: From: 06-01-80 To: 06-01-81
Project/Area/Task: Silicon Cells
Contract Funding: FY80 $60,000 FY $ FY $ FY $
Cumulative Funding To Date: $60,000

Contract objectives are to give analytical support for concentrator cell development; develop p^+-n-n^+ solar cell; and experimentally and theoretically examine some new design concepts, especially HLE solar cell. Final report has been received and is in review.

Title:	Residential Reference Design Development	**Contract Number:**	13-8779
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Gary J. Jones	**Telephone:**	(505) 844-2433
Contractor:	General Electric Co. Space Systems Division Valley Forge, PA		
Principal Investigator:	E. M. Mehalick	**Telephone:**	(215) 962-5842
Contract Period of Performance:	**From:** 08-02-79 **To:** 01-31-81		
Project/Area/Task:	Conceptual Design & Optimization		
Contract Funding:	FY79 $366,900 FY80 $72,600	FY $	FY $
Cumulative Funding To Date:	$439,500		

The contractor is to review all residential photovoltaic systems work done to date. Based on these data and supplementary analysis, nine designs spread over three regions represent the most viable systems and cover the technology options. Six of these were chosen for a preliminary design phase indicating all necessary electrical and mechanical hardware and their specifications. This work is in direct support of the residential test and application program forming the input to the regional appropriate system designs. In addition these results will be used for detailed system costing studies and other DOE activities.

Three design reports have been published: SAND79-7056, SAND80-7148, and SAND80-7170. The last three are in review and should be published in late 1981 and early 1982. The last three designs cover a passive/PV residence in the northeast, a southeast residence, and a design for a temperate climate (no space conditioning load), respectively.

Title:	Concentrator Cell Assembly Development	**Contract Number:**	13-8893
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. T. Weaver	**Telephone:**	(505) 844-8979
Contractor:	General Electric Advanced Energy Program P.O. Box 8661 Philadelphia, PA 19101		
Principal Investigator:	Neal Shepard	**Telephone:**	(518) 385-3473
Contract Period of Performance:	**From:** 09-25-79 **To:** 07-30-81		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY79 $343,200 FY80 $127,598	FY $	FY $
Cumulative Funding To Date:	$470,798		

Contract objective is to develop a vertical junction solar cell. This contract will permit the evaluation of GE's concept for high concentration Si cells using pyramidal, etched pockets for contacts from the back side. The contract has been completed, and the final report received.

Title:	High Concentration Module Development	**Contract Number:**	13-9434
Directing Organization:	Sandia National Laboratories		
Project Engineer:	E. C. Boes	**Telephone:**	(505) 844-5634
Contractor:	General Electric Advanced Energy Department P.O. Box 8661 Philadelphia, PA 19101		
Principal Investigator:	Ron Hodge	**Telephone:**	(215) 962-5949
Contract Period of Performance:	**From:** 01-14-80 **To:** 11-30-81		
Project/Area/Task:	Concentrator Module Development		
Contract Funding:	FY80 $315,000 FY $	FY $	FY $
Cumulative Funding To Date:	$315,000		

The objective of this program is to design and demonstrate via prototype hardware a high efficiency ($\geq$15%) high concentration ratio (400-2000X) photovoltaic module. The prototype module was tested at GE and delivered to Sandia. Test results indicate efficiencies of about 12%, with the primary limitation on module efficiency being the EMVJ cell efficiency.

The draft final report delivered in the fourth quarter of FY 1981 is being reviewed at Sandia.

Title:	Energy Scenario Effects Study	**Contract Number:**	13-9482
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Gary J. Jones	**Telephone:**	(505) 844-2433
Contractor:	General Electric 1 River Road Schenectady, NY 12345		
Principal Investigator:	Gary Bonk	**Telephone:**	(518) 385-4097
Contract Period of Performance:	**From:** 04-01-80 **To:** 10-15-81		
Project/Area/Task:	Applications Analysis		
Contract Funding:	FY80 $401,600 FY $	FY $	FY $
Cumulative Funding To Date:	$401,600		

The work should result in a broad coverage of possible utility rate scenarios, identifying significant parameters and explaining their PV system impact.

- Task I - Identify and describe a group of generic PV system configurations representing current possibilities.
- Task II - Identify and describe a range of electric utility energy source scenarios using variations in assumptions on causal effects, economic and operational specifics, and all other reasonable eventualities.
- Task III - Determine the scenarios' effects on PV system design and operation. Bulk of the effort is in this task area.

The final report is currently under review. It is expected that publication of results will occur in early 1982.

Title:	Laminated Glass-Acrylic Fresnel Lens Development	**Contract Number:**	46-0063
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	General Electric, Space Div. P.O. Box 8661 Philadelphia, PA 19101		
Principal Investigator:	R. B. Hobbs, Jr.	**Telephone:**	(215) 962-5949
Contract Period of Performance:	**From:** 10-18-79 **To:** 07-31-80		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY80 $171,800 FY $	FY $	FY $
Cumulative Funding To Date:	$171,800		

Contract objectives are to develop and fabricate laminated point focus Fresnel lenses using injection molded lenses bonded to glass.

Contract is complete. Optical quality of lenses produced was not good. Evaluation indicated that changes to the lens design and the injection molding process should improve lens optical quality.

Title:	Small Commercial Applications	**Contract Number:**	62-7317
Directing Organization:	Sandia National Laboratories		
Project Engineer:	D. L. Caskey	**Telephone:**	(505) 844-7704
Contractor:	General Electric Space Division P.O. Box 8555 Philadelphia, PA 19101		
Principal Investigator:	Jay Herz	**Telephone:**	(215) 962-5826
Contract Period of Performance:	**From:** 10-14-80 **To:** 01-14-82		
Project/Area/Task:	Applications Analysis		
Contract Funding:	FY81 $350,000 FY $	FY $	FY $
Cumulative Funding To Date:	$350,000		

Contract objective is to determine, for specific geographic regions, the most promising applications for small PV installations in the range of 20 - 300 kW_p. Contract is in process, technical work is nearly finished.

Title:	Laminated Glass-Acrylic Fresnel Lens Development	**Contract Number:**	62-9975
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	General Electric Space Div. P. O. Box 8661 Philadelphia, PA 19101		
Principal Investigator:	R. Hodge	**Telephone:**	(215) 962-5949
Contract Period of Performance:	**From:** 10-20-81 **To:** 02-15-82		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY81 $172,376 FY $	FY $	FY $
Cumulative Funding To Date:	$172,376		

Contract objectives are to extend work on injection molded laminated point focus Fresnel lenses performed under contract 46-0036 and to fabricate 5 x 6 lens parquets of point focus photovoltaic concentrator arrays.

Lens design was chosen in June. Injection molding process was started late September. Lens to glass lamination machine is in design.

Title:	Initial Detailed Designs for Intermediate PV Systems	**Contract Number:**	74-0800
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	General Electric Company P. O. Box 8661 Philadelphia, PA 19101		
Principal Investigator:	J. Herz	**Telephone:**	(215) 962-5826
Contract Period of Performance:	**From:** 01-07-81 **To:** 03-07-82		
Project/Area/Task:	Conceptual Design and Optimization		
Contract Funding:	FY81 $343,000 FY $	FY $	FY $
Cumulative Funding To Date:	$343,000		

Contract objectives are to produce four detailed reference designs of PV intermediate systems, and prepare final summary report.

First design is complete. Will be published by December 30, 1981. Work is in progress on remaining designs and final summary.

Title:	Acrylic Fresnel Lens Parquet Fabrication	**Contract Number:**	74-4454
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	General Electric Co. Valley Forge Space Center P.O. Box 8661 Philadelphia, PA 19101		
Principal Investigator:	R. Hodge	**Telephone:**	(215) 962-5949
Contract Period of Performance:	**From:** 01-15-81 **To:** 10-15-81		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY81 $59,940 FY $	FY $	FY $
Cumulative Funding To Date:	$59,940		

Contract objective is to fabricate 50 ea 6 x 5 lens parquets for use with TR81 strawman PV module. Specific lens design was specified in June. The 30 lens "mother" electroforms are complete and the lens parquet master is being assembled.

Title:	PV Array Field Optimization and Modularity Study	**Contract Number:**	62-9188
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. N. Post	**Telephone:**	(505) 844-2154
Contractor:	Hughes Aircraft Company P. O. Box 90515 Los Angeles, CA 90009		
Principal Investigator:	G. J. Naff	**Telephone:**	(213) 670-1515
Contract Period of Performance:	**From:** 01-12-81 **To:** 11-11-81		
Project/Area/Task:	Array Subsystem Development		
Contract Funding:	FY81 $485,700 FY $	FY $	FY $
Cumulative Funding To Date:	$485,700		

The overall objective is to reduce the cost of medium-sized PV array fields by reducing the cost of structural and electrical subsystem designs, their components, and their installation. Subsystems to be investigated include the support structure, foundation, site preparations, field wiring, grounding, and lightning protection. The low-cost designs to be developed are to be for flat-panel, ground-mounted arrays and are to be applicable for near-term implementation to reduce balance-of-system costs.

Subsystem requirements and design criteria have been established and documented. Optimized array field designs for 20-kW, 100-kW, and 500-kW systems have been completed. Array field BOS costs for these integrated and modular designs are estimated at $55/m^2$ of collector area.

Title:	Cell Assembly Development	**Contract Number:**	40-1094
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. M. Garner	**Telephone:**	(505) 844-2351
Contractor:	International Rectifier 233 Kansas Street El Segundo, CA 90245		
Principal Investigator:	Ronald Schuetze	**Telephone:**	(213) 772-2000
Contract Period of Performance:	**From:** 02-28-81 **To:** 03-01-82		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY81 $183,700 FY $	FY $	FY $
Cumulative Funding To Date:	$183,700		

Contract objectives are to design and fabricate cell assemblies which provide a high thermal and electrical conductance stress barrier between the solar cell and the copper stud mount. Subject the cell assembly to accelerated life test.

Deliver: Ten complete prototype stud mount assemblies to Sandia.

Have fabricated copper studs and graphite jigs to hold assembly in place while soldering. Have assembled a Moly to Cu cell using 290°C solder with good adhesion. Presently investigating soldering the front contacts to the cell.

Title:	Study of Energy Performance of a Hybrid-Electric Automobile with a Photovoltaic Residence	**Contract Number:**	49-1533
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Gary J. Jones	**Telephone:**	(505) 844-2433
Contractor:	JSR Associates 2280 Hanover St. Palo Alto, CA 94306		
Principal Investigator:	John S. Reuyl	**Telephone:**	(415) 329-9289
Contract Period of Performance:	**From:** 03-17-80 **To:** 12-31-80		
Project/Area/Task:	Conceptual Design & Optimization		
Contract Funding:	FY80 $43,900 FY81 $12,500	FY $	FY $
Cumulative Funding To Date:	$56,400		

Contract objectives are the following:

- Design a hybrid-electric automobile that can interface with a PV residence.
- Provide candidate residential designs from other studies, review these designs, and select one for study.
- Conduct a preliminary study of the energy performance of the automobile and the residence involving both stand-alone residential applications as well as residences with electric grid hookups.

The final report has been received and is undergoing final corrections prior to publication as SAND81-7044.

Title:	Lens Design Programs	**Contract Number:**	61-3451
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	L. W. James & Associates 1525 E. County Rd. 58 Fort Collins, CO 80524		
Principal Investigator:	Dr. Larry James	**Telephone:**	(303) 484-5296
Contract Period of Performance:	**From:** 04-10-81 **To:** 09-15-81		
Project/Area/Task:	Concentrator Concept Development		
Contract Funding:	FY81 $17,140 FY $	FY $	FY $
Cumulative Funding To Date:	$17,140		

Contract objective is to lease to Sandia Fresnel Lens design and parabolic trough design programs that run on the HP 9845B/C desktop computers. All programs were delivered by September 15, 1981.

Title:	Second Generation Point Focus Fresnel Lens Module	**Contract Number:**	46-3018
Directing Organization:	Sandia National Laboratories		
Project Engineer:	M. W. Edenburn	**Telephone:**	(505) 844-4003
Contractor:	Martin Marietta Box 179 Denver, CO 80201		
Principal Investigator:	Sid Broadbent	**Telephone:**	(303) 789-1533
Contract Period of Performance:	**From:** 01-31-80 **To:** 01-31-81		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY80 $353,300 FY $	FY $	FY $
Cumulative Funding To Date:	$353,300		

The first generation point focus concentrator array fabricated by Martin Marietta has been one of best performing units fabricated to date. The present contract calls for Martin Marietta to keep the same overall array concept, while optimizing the components of the array. The goal was to have an array which could clearly meet the $2.80/W_p$ goal.

Three Martin Marietta second generation modules (14 lenses and cells each) were received on October 30. Their performance and durability will be tested beginning in November at Sandia's PASTF.

Title:	Reference Design for a Photovoltaic Central Power Station	**Contract Number:**	62-9142
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Gary J. Jones	**Telephone:**	(505) 844-2433
Contractor:	Martin Marietta Corporation Solar Energy Systems P.O. Box 179 Denver, CO		
Principal Investigator:	Matthew Imamura	**Telephone:**	(303) 977-0701
Contract Period of Performance:	**From:** 06-11-81 **To:** 09-10-82		
Project/Area/Task:	Photovoltaic Conceptual Design & Optimization		
Contract Funding:	FY81 $383,000 FY $	FY $	FY $
Cumulative Funding To Date:	$383,000		

The contractor, in conjunction with his utility subcontractor, is to first define the requirements for the designs to be developed. These are to include those features desired by the utility as well as PV technical aspects. Two designs are to then be developed using this document. The first will be for flat panel arrays, the second for concentrators.

The draft requirements document and Task 1 report were received on schedule in the last half of September 1981.

Title:	Cell-Substrate Bonding System Development	**Contract Number:**	68-0490
Directing Organization:	Sandia National Laboratories		
Project Engineer:	L. C. Beavis	**Telephone:**	(505) 844-2231
Contractor:	Martin Marietta P. O. Box 179 Denver, CO 80201		
Principal Investigator:	Bob Hein	**Telephone:**	(303) 977-0718
Contract Period of Performance:	**From:** 08-11-81 **To:** 11-30-82		
Project/Area/Task:			
Contract Funding:	FY81 $85,000 FY $	FY $	FY $
Cumulative Funding To Date:	$85,000		

Contract objectives are to develop new bonding (cell laydown) system, with emphasis on thermal grease-thermal link.

Task I & II - requires report first quarter FY 1982.
Task III & IV - report due third quarter FY 1982.
Final report due fourth quarter FY 1982.

This work is presently behind schedule because the principal investigator left Martin Marietta, Denver, shortly after work started (early September) and an environmental oven failed, destroying samples in November. Efforts are being made to catch up to schedule. Thermal greases with unique mechanical mounts are principal systems being investigated.

Title: Low-Cost Two-Axis Tracking Structure Development
Contract Number: 74-2888
Directing Organization: Sandia National Laboratories
Project Engineer: A. B. Maish
Telephone: (505) 844-8771
Contractor: Martin Marietta
P.O. Box 179
Denver, Co 80201
Principal Investigator: Sid Broadbent
Telephone: (303) 977-9686
Contract Period of Performance: **From:** 03-24-81 **To:** 08-31-82
Project/Area/Task: Array Subsystems
Contract Funding: FY81 $227,600 FY $ FY $ FY $
Cumulative Funding To Date: $227,600

Contract objective is to develop a 2nd generation pedestal tracking structure to support MMC 2nd generation modules. Hardware will be delivered including alt/az drive unit, torque tube with mounting holes for 2nd generation modules, new STU microprocessor control unit and sun sensor.

Included in the design effort is a cost analysis of 5 alternative array/drive combinations, a wind tunnel test of the leading candidate array, and test to failure (strength) of the azimuth drive unit (a SOLERAS unit).

As of January 8, 1982, cost analysis and wind tunnel tests have been completed. The results indicate a SOLERAS drive unit with a highly porous array of 2nd generation MMC modules is the most cost effective approach. Drive unit tests are scheduled for early February 1982. Array structure delivery still scheduled for May 1982.

Title: Weatherability of Sheet Moulding Compounds Study
Contract Number: 74-0765
Directing Organization: Sandia National Laboratories
Project Engineer: N. H. Clark
Telephone: (505) 844-8531
Contractor: Massachusetts Institute of Technology
Dept. of Mat. Sci. & Engr.
77 Mass Ave.
Cambridge, MA 02139
Principal Investigator: David Roylance
Telephone: (617) 253-3309
Contract Period of Performance: **From:** 09-30-80 **To:** 09-30-81
Project/Area/Task: Manufacturing Development
Contract Funding: FY81 $49,000 FY $ FY $ FY $
Cumulative Funding To Date: $49,000

Contract objective is to determine the weatherability of sheet moulding compounds as a substrate material for reflective solar concentrators, especially as molded parabolic trough substrates for silvered glass reflectors. In particular, determine whether these are mechanically stable in typical outdoor environs. Final report due the second quarter of FY 1982 is in preparation.

Title:	Legal and Institutional Issues of Photovoltaics	**Contract Number:**	62-3996
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	Mel Eisenstadt & Associates 7800 Phoenix, NE Albuquerque, NM 87110		
Principal Investigator:	M. Eisenstadt	**Telephone:**	(505) 296-2956
Contract Period of Performance:	**From:** 05-07-80 **To:** 05-06-81		
Project/Area/Task:	Sandia AOP Applications Analysis		
Contract Funding:	FY80 $30,000 FY $	FY $	FY $
Cumulative Funding To Date:	$30,000		

Contract objective is to provide legal evaluation as required on zoning, building ordinances, warranties, and government regulations impacting photovoltaics.

Work is completed. Following reports have been published:

SAND80-7080-"Effect of PURPA on PV systems"
SAND80-7081-"Solar Access"
SAND81-7008-"PV Warranties"
SAND81-7034-"Effect of Standards on PV Liability"

Title:	Pulse Testing of Cells-Lightning Effect Simulation	**Contract Number:**	62-8208
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Rogers	**Telephone:**	(505) 844-8738
Contractor:	Mission Research Corporation 1400 San Mateo SE, Suite A Albuquerque, NM 87108		
Principal Investigator:	Ron Pease	**Telephone:**	(505) 265-8306
Contract Period of Performance:	**From:** 10-07-80 **To:** 12-31-81		
Project/Area/Task:	Engineering Development		
Contract Funding:	FY81 $90,454 FY $	FY $	FY $
Cumulative Funding To Date:	$90,454		

Contract objective is to determine the vulnerability of solar cells to lightning induced transients. Equations and a computer model have been developed to describe phenomena. Approximately one-half of the testing at the Air Force Weapons Laboratories has been completed.

Title:	On-Site Data Acquisition System Services	**Contract Number:**	49-4911
Directing Organization:	Sandia National Laboratories		
Project Engineer:	T. L. Evans	**Telephone:**	(505) 844-8867
Contractor:	Mississippi Co. Comm. College South Highway 61 Blytheville, Arkansas 72315		
Principal Investigator:	Dr. Harry Smith	**Telephone:**	(501) 762-1020
Contract Period of Performance:	**From:** 08-01-80 **To:** 04-01-81		
Project/Area/Task:	On-Site Data Hardware		
Contract Funding:	FY80 $37,700 FY $	FY $	FY $
Cumulative Funding To Date:	$37,700		

Contract objectives are to:

- Provide site application software for On-Site Data Acquisition System (ODAS).
- Provide for installation, wiring, and checkout of ODAS and meteorological station.
- Provide maintenance for weather station instruments for two years.
- Allow data from photovoltaic project to be collected by Photovoltaic Data Reduction Center.

Contract completed September 30, 1981. All hardware installed and system operational. No further activity on this contract anticipated.

Title:	On-Site Data Acquisition System Services	**Contract Number:**	49-4912
Directing Organization:	Sandia National Laboratories		
Project Engineer:	T. L. Evans	**Telephone:**	(505) 844-8867
Contractor:	NW Mississippi Junior College Highway 51 North Senatobia, Mississippi 38668		
Principal Investigator:	Dr. June Gardner	**Telephone:**	(601) 562-5262
Contract Period of Performance:	**From:** 08-01-80 **To:** 04-01-81		
Project/Area/Task:	On-Site Data Hardware		
Contract Funding:	FY80 $43,700 FY $	FY $	FY $
Cumulative Funding To Date:	$43,700		

Contract objectives are to:

- Provide site application software for On-Site Data Acquisition System (ODAS).
- Provide for installation, wiring, and checkout of ODAS and meteorological station.
- Provide maintenance for weather station instruments for two years.
- Allow data from photovoltaic project to be collected by Photovoltaic Reduction Center.

Work on contract halted indefinitely with "Stop Work Order" through purchasing, because of no funding for balance of photovoltaic system. Resumption of work on this contract awaiting outcome of NWJC negotiations with DOE for further funding.

Title:	Silicon Concentrator Cell Production		**Contract Number:** 28-1065		
Directing Organization:	Sandia National Laboratories				
Project Engineer:	R. D. Nasby		**Telephone:** (505) 844-6137		
Contractor:	Motorola 5005 East McDowell Rd. Phoenix, AZ				
Principal Investigator:	Larry Grenom		**Telephone:** (602) 244-6414		
Contract Period of Performance:	**From:** 05-01-80 **To:** 05-01-81				
Project/Area/Task:	Silicon Cells				
Contract Funding:	FY80 $197,800	FY81 $2,200	FY $	FY $	
Cumulative Funding To Date:	$200,000				

The objective of this contract is to improve the efficiency of silicon solar cells using advanced processing methods and to look at totally plated metallization systems.

This is an extension of contract #13-6121.

Awaiting final report due the first quarter of FY 1982.

Title:	Cell Mount Design		**Contract Number:** 40-0665		
Directing Organization:	Sandia National Laboratories				
Project Engineer:	Ben Rose		**Telephone:** (505) 844-7864		
Contractor:	Motorola Inc. Gov. Elec. Div. (GED) 8201 East McDowell Rd. Scottsdale, AZ 85252				
Principal Investigator:	Keith Kingston		**Telephone:** (602) 949-3003		
Contract Period of Performance:	**From:** 02-28-81 **To:** 03-01-82				
Project/Area/Task:	Silicon Cells				
Contract Funding:	FY81 $238,600	FY $	FY $	FY $	
Cumulative Funding To Date:	$238,600				

The primary project goals are 1) to advance the technology of a low-cost cell mount incorporating a metal or other cost-effective substrate, 2) assemble and test about 100 mounts, using metal, clad metal, and insulating substrates, 3) determination of best evaluation technique for detecting solder voids, cracks, and delaminations, 4) environmental test and evaluation of assembled mounts.

All of the above project goals have been completed. The final report is to be submitted for review in January 1982.

Title:	Solar Cell Development	**Contract Number:**	40-0650
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Jose Rodriguez	**Telephone:**	(505) 844-6137
Contractor:	Sensor Technology (Photowatt) 2414 W. 14th St. Tempe, AZ 85281		
Principal Investigator:	Mike Keeling	**Telephone:**	(602) 894-9564
Contract Period of Performance:	**From:** 02-01-81 **To:** 07-01-82		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY81 $349,100 FY $ FY $ FY $		
Cumulative Funding To Date:	$349,100		

Contract objective is fabrication of $p^+ nn^+$ silicon concentrator solar cells in production facility. The main objective is to be accomplished via the following tasks.

1. Transfer of technology
2. Modify baseline process
3. Laboratory scale production
4. Test product and verify process
5. Pilot line production
6. Evaluation of product
7. Process modification
8. Large batch production
9. Deliverables

Project is active.

Task 1. Has been completed.
2. Has been completed.
3. Has been completed with contact resistance problems encountered along with solutions to them and also some Boron masking problems identified.
4. Has been completed with plans to modify process and perform joint experiments to improve product.
5. Is partially on-going with further action pending results of task 4.
6. Partially on-going.
7. No action.
8. No action.
9. Monthly reports delivered. Four of 25 cells delivered.

Title:	An Integrated Back Contact Solar Cell for Use in Concentrated Sunlight	**Contract Number:**	13-2304
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. M. Garner	**Telephone:**	(505) 844-2351
Contractor:	Purdue University School of Electrical Engineering West Lafayette, IN 47907		
Principal Investigator:	Richard Schwartz	**Telephone:**	(317) 749-2467
Contract Period of Performance:	From: 01-18-79 To: 01-18-81		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY79 $149,800 FY $	FY $	FY $
Cumulative Funding To Date:	$149,800		

Contract objectives are the following:

- To perform analysis of IBC cells produced at Sandia Laboratories and suggest design changes to improve the performance of the cells.
- To provide computer simulation of solar cell performance on request.
- To formalize the design for a combination silicon-germanium double junction cell.

Contract is complete. Final report received in the second quarter of FY 1981 and printed.

Title:	IBC Cell Development	**Contract Number:**	40-0710
Directing Organization:	Sandia National Laboratories		
Project Engineer:	H. T. Weaver	**Telephone:**	(505) 844-8979
Contractor:	Purdue University School of Electrical Engineering West Lafayette, IN 47907		
Principal Investigator:	R. J. Schwartz	**Telephone:**	(317) 494-3510
Contract Period of Performance:	From: 02-28-81 To: 03-01-82		
Project/Area/Task:	Silicon Cells		
Contract Funding:	FY81 $100,000 FY $	FY $	FY $
Cumulative Funding To Date:	$100,000		

Contract objectives include analysis of IBC solar cell behavior and development of two dimension computer code for transport analysis in solar cells.

Project is active. The code will be ready for initial check out in early 1982. It will be applied to such advanced Si cell concepts as IBC, EMVJ, and pocket cells.

Title:	Dynamic Simulation of Dispersed Grid-Connected PV Systems	**Contract Number:**	62-4092
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Dahwey Chu	**Telephone:**	(505) 846-2457
Contractor:	Purdue Research Foundation Hovde Hall Purdue University West Lafayette, IN 47907		
Principal Investigator:	O. Wasquczuk, P. Krause	**Telephone:**	(317) 494-3475
Contract Period of Performance:	**From:** 05-21-81 **To:** 08-31-82		
Project/Area/Task:	Task 3 Power Conditioning and Control		
Contract Funding:	FY81 $120,000 FY82 $108,085	FY $	FY $
Cumulative Funding To Date:	$228,085		

Contract involves development of PV system models simulation and interpretation of PV system both individually and collectively in typical distribution networks. Simulation of the collected effects of the systems on utility grids. The project is underway.

Title:	Analysis of Low Density PV Applications	**Contract Number:**	62-8255
Directing Organization:	Sandia National Laboratories		
Project Engineer:	D. L. Caskey	**Telephone:**	(505) 844-7704
Contractor:	Research Triangle Institute Research Triangle Park, NC 27709		
Principal Investigator:	Carl Parker	**Telephone:**	(919) 541-5876
Contract Period of Performance:	**From:** 12-03-80 **To:** 03-03-82		
Project/Area/Task:	Applications Analysis		
Contract Funding:	FY81 $176.2K FY $	FY $	FY $
Cumulative Funding To Date:	$176.2K		

Contract objective is to determine promising grid-connected PV applications characterized by low electrical energy density consumption where a roof-mounted PV array could supply a fraction of the building's electrical load. Work is in progress.

Title:	Study Customer/Utility Own Electric Storage for PV Systems	**Contract Number:**	62-9952
Directing Organization:	Sandia National Laboratories		
Project Engineer:	David L. Caskey	**Telephone:**	(505) 844-7704
Contractor:	Research Triangle Institute Research Triangle Park, NC 27709		
Principal Investigator:	Dr. George Ferrell	**Telephone:**	(919) 541-5824
Contract Period of Performance:	**From:** 02-05-81 **To:** 05-05-82		
Project/Area/Task:	Power Conditioning & Control		
Contract Funding:	FY81 $182K FY $	FY $	FY $
Cumulative Funding To Date:	$182K		

Contract objective is to determine the relative merits of customer versus utility location, ownership, and control of electrical storage. Work is in process.

Title: Efficiency Improvement Study for GaAs Solar Cells
Contract Number: 49-1792
Directing Organization: Sandia National Laboratories
Project Engineer: J. J. Wiczer
Telephone: (505) 844-9677
Contractor: Rockwell International
Electronics Research Center
P.O. Box 1085
Thousand Oaks, CA 91360
Principal Investigator: John Cape
Telephone: (805) 498-4545
Contract Period of Performance: **From:** 03-30-80 **To:** 04-01-81
Project/Area/Task:
Contract Funding: FY80 $375,000 FY $ FY $ FY $
Cumulative Funding To Date: $375,000

Contract objective is to study efficiency correlation with GaAs substrate properties. The goal of this work was to correlate substrate quality and fabrication process steps with the ultimate photovoltaic conversion efficiency achieved for various cell structures. A series of different starting material substrates were investigated.

Ten cells have been received. Rough draft of final report has been completed although not yet received at Sandia. Final report has been received and with some modifications accepted. Task 6 has been completed. Task 5 has been completed although Sandia has not performed independent measurements on cell efficiencies yet. Task 4 has been completed. Task 3 completed. Task 2 has been completed. Task 1 complete. Work on 49-1792 has essentially been completed.

Title: Phase II, San Bernardino CDC
Contract Number: 62-8225
Directing Organization: Sandia National Laboratories
Project Engineer: Haskins
Telephone: (505) 844-7790
Contractor: San Bernardino West Side Community Development Corp.
1736 W. Highland Ave.
San Bernardino, CA 92411
Principal Investigator: Dwayne Burgess
Telephone: (714) 887-2546
Contract Period of Performance: **From:** 10-1-80 **To:** 12-21-81
Project/Area/Task: Project Management
Contract Funding: FY81 $983,400 FY $ FY $ FY $
Cumulative Funding To Date: $850,400

Contract objectives are to design and install a 35-kW photovoltaic system on the roof of a light industrial building. System to interface with utility grid with sellback on weekends and holidays. Project delayed three months due to slip in module deliveries. Completion projected December 31, 1981.

Title: Silicon Solar Cell Development
Contract Number: 46-2042B
Directing Organization: Sandia National Laboratories
Project Engineer: H. T. Weaver
Telephone: (505) 844-8979
Contractor: Solarex Corporation
1335 Piccard Dr.
Rockville, MD 20850
Principal Investigator: John Wohlgemuth
Telephone: (301) 948-0202
Contract Period of Performance: **From:** 07-01-80 **To:** 01-01-81
Project/Area/Task: Silicon Cells
Contract Funding: FY80 $42,000 FY $ FY $ FY $
Cumulative Funding To Date: $42,000

Contract objective is to attach cells to unit assemblies. Contract is complete, except awaiting final report due in the first quarter of FY 1982.

Title: Cell Assembly Studies
Contract Number: 46-2259
Directing Organization: Sandia National Laboratories
Project Engineer: H. T. Weaver
Telephone: (505) 844-8979
Contractor: Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
Principal Investigator: John Wohlgemuth
Telephone: (301) 948-0202
Contract Period of Performance: **From:** 07-01-80 **To:** 09-30-81
Project/Area/Task: Silicon Cells
Contract Funding: FY81 $234,600 FY $ FY $ FY $
Cumulative Funding To Date: $234,600

Contract objective is to develop methods for attaching silicon cells to heat sinks. A key aspect of this work is a subcontract with Dow Corning to help identify and characterize candidate adhesives.

Contract is in progress. A number of electrically insulating adhesives were tested for durability and thermal conductivity. The best candidates have been identified. Contract is nearly complete. Report is in progress.

Title: Silicon Solar Cell Development
Contract Number: 46-2042C
Directing Organization: Sandia National Laboratories
Project Engineer: H. T. Weaver
Telephone: (505) 844-8979
Contractor: Spire Corporation
Patriots Park
Bedford, MA 01730
Principal Investigator: John A. Minnucci
Telephone: (617) 275-6000
Contract Period of Performance: **From:** 07-01-80 **To:** 01-01-81
Project/Area/Task: Silicon Cells
Contract Funding: FY80 $74,000 FY $ FY $ FY $
Cumulative Funding To Date: $74,000

Contract objective is to put cells onto linear assembly. This contract would populate some of the blank linear receivers on the Spectrolab 10-kW array, for possible comparison purposes. Work is in progress, assemblies are still to be received.

Title: IBC Cell Development
Contract Number: 49-2715
Directing Organization: Sandia National Laboratories
Project Engineer: H. T. Weaver
Telephone: (505) 844-8979
Contractor: Spire Corporation
Patriots Park
Bedford, MA 01730
Principal Investigator: John A. Minnucci
Telephone: (617) 275-6000
Contract Period of Performance: From: 05-01-80 To: 05-01-81
Project/Area/Task: Silicon Cells
Contract Funding: FY80 $202,800 FY $ FY $ FY $
Cumulative Funding To Date: $202,800

Contract objective is to fabricate a silicon cell with metal contacts only on one side. The cell is essentially an interdigitated back contact cell fabricated using ion implanation techniques. Work is in progress, awaiting final report due the first quarter of FY 1982. Cells have been received.

Title: Preliminary Design of a Commercial- Stand-Alone Dual Axis Concentrator Array
Contract Number: 61-3333
Directing Organization: Sandia National Laboratories
Project Engineer: J. L. Jackson
Telephone: (505) 844-7825
Contractor: Sun-Trac Corporation
P.O. Box 96
Glenview, IL 60025
Principal Investigator: J. Fromeyer
Telephone: (312) 256-2510
Contract Period of Performance: From: 05-27-81 To: 07-27-82
Project/Area/Task: Sandia AOP Array Design & Fabrication
Contract Funding: FY81 $22,000 FY $ FY $ FY $
Cumulative Funding To Date: $22,000

Contract objectives are to develop a list of design requirements for a commercial stand-alone PV dual axis concentrator array; furnish isometric drawings for completed preliminary design using existing technology; and fabricate one or more modules of systems for that purpose. Design requirements definition and preliminary component testing are underway.

Title:	Laminated Glass-Acrylic Fresnel Lens Development	**Contract Number:**	13-5165
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	Swedlow, Inc. Electric Space Div. 12122 Western Ave. Garden Grove, CA 92645		
Principal Investigator:	Lawrence A. Matalon	**Telephone:**	(714) 893-7531
Contract Period of Performance:	**From:** 09-25-79 **To:** 12-31-81		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY79 $106,500 FY $	FY $	FY $
Cumulative Funding To Date:	$106,500		

Contract objectives are to develop a laminated glass/plastic Fresnel lens for use in point focus photovoltaic concentrators. Original techical work was completed under budget. Contract was extended to allow further work consistent with authorized funds.

Title:	Solid Acrylic Lens Production Development	**Contract Number:**	13-5166
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. B. Stillwell	**Telephone:**	(505) 844-2130
Contractor:	Swedlow, Inc. 12122 Western Ave. Garden Grove, CA 92645		
Principal Investigator:	Craig Childers	**Telephone:**	(714) 893-7531
Contract Period of Performance:	**From:** 09-15-79 **To:** 07-30-81		
Project/Area/Task:	Array Design and Fabrication		
Contract Funding:	FY79 $101,900 FY $	FY $	FY $
Cumulative Funding To Date:	$101,900		

Contract objectives are to design and fabricate a 5 X 5 lens parquet of solid acrylic Fresnel point focus lenses for use in a point focus photovoltaic concentrator module. Contract is complete.

Title:	Advanced PCS Concepts Study	**Contract Number:**	74-5898
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. M. Coats	**Telephone:**	(505) 844-5206
Contractor:	Teslaco, Inc. 490 South Rosemead Blvd, Suite 6 Pasadena, CA 91107		
Principal Investigator:	R. D. Middlebrook	**Telephone:**	(213) 795-1699
Contract Period of Performance:	**From:** 07-01-81 **To:** 07-01-82		
Project/Area/Task:	Power Conditioning and Control/PCS Hardware Development		
Contract Funding:	FY81 $162,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$162,000		

Contract objectives are to select optimal module size and topology for residential size inverters; build and test breadboard; perform detailed design including control circuitry and maximum power tracking, build and evaluate final unit; and publish final report.

Topology and optimal module size have been selected. Breadboard has been built and tested in a resistive load. Contractor is in detailed design phase.

Title:	Hail Monitor Development & Deployment	**Contract Number:**	28-8679
Directing Organization:	Sandia National Laboratories		
Project Engineer:	R. Hayenga	**Telephone:**	(505) 844-2701
Contractor:	Texas Tech University Dept. of Industrial Engr. P. O. Box 4130 Lubbock, TX 79409		
Principal Investigator:	Dr. Milton Smith	**Telephone:**	(806) 742-3404
Contract Period of Performance:	**From:** 10-01-80 **To:** 09-30-81		
Project/Area/Task:	Data Acquisition System & On Site Monitoring		
Contract Funding:	FY81 $44,200 FY $ FY $ FY $		
Cumulative Funding To Date:	$44,200		

Contract objectives are to deploy, replace as necessary, and provide data readout of hail monitoring devices at photovoltaic system application experiment sites.

Hail pads were installed at 12 PV sites. At the end of FY 1981 contract 28-8679 was terminated and was replaced with a new contract, #16-0895.

Title:	Cost Methodology Development	**Contract Number:**	46-5760
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Gary J. Jones	**Telephone:**	(505) 844-2433
Contractor:	Theodore Barry & Associates 1520 Wilshire Blvd. Los Angeles, CA 90017		
Principal Investigator:	R. J Bullemer	**Telephone:**	(213) 413-6080
Contract Period of Performance:	**From:** 01-07-80 **To:** 12-15-81		
Project/Area/Task:	Conceptual Design & Optimization		
Contract Funding:	FY80 $358,400 FY $	FY $	FY $
Cumulative Funding To Date:	$358,400		

Contract involves development of: 1) cost account structure for large photovoltaic systems; 2) modification of SAMIS computer code to handle power conditioning and concentrator technologies; and 3) computerization of an existing Marketing and Distribution Cost Model.

The reports, currently under review, include;
1. Cost Accounting and Reporting Manual
2. Marketing and Distribution User Manual
3. Marketing and Distribution Programmers Manual
4. "SAMIS" User Manual
5. Project Final Report.

Title:	Photovoltaic System Installation Cost Elements	**Contract Number:**	49-8435
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. L. Jackson	**Telephone:**	(505) 844-7825
Contractor:	Theodore Barry & Associates 1520 Wilshire Blvd. Los Angeles, CA 90017		
Principal Investigator:	Bob Bullemer	**Telephone:**	(213) 413-6080
Contract Period of Performance:	**From:** 07-17-80 **To:** 07-17-81		
Project/Area/Task:	Engineering Support		
Contract Funding:	FY80 $203,000 FY $	FY $	FY $
Cumulative Funding To Date:	$203,000		

Contract objectives are to:

- Select candidate PV systems for given structures in the residential and intermediate sectors.
- Estimate post-factory PV costs for candidate systems assuming new construction.
- Estimate post-factory PV costs for candidate systems assuming retrofit of PV systems.
- Propose cost reduction techniques and assess their impact on cost estimates developed for new and retrofit construction.

Work is completed. SAND81-7014 is published.

Title: High Concentration Module Development
Contract Number: 13-9436
Directing Organization: Sandia National Laboratories
Project Engineer: E. C. Boes
Telephone: (505) 844-5634
Contractor: Thermo-Electron
101 First Ave.
Waltham, MA 02154
Principal Investigator: R. Scharlack
Telephone: (617) 890-8700
Contract Period of Performance: **From:** 12-06-79 **To:** 11-30-81
Project/Area/Task: Concentrator Module Development
Contract Funding: FY80 $275,900 FY81 $117,000 FY $ FY $
Cumulative Funding To Date: $392,900

The two primary objectives are to:

- Demonstrate the feasibility of a high concentration and high efficiency PV module using domed acrylic Fresnel lenses and Si cells.
- Investigate the possibility of injection molding of domed acrylic lenses.

Breadboard module testing is underway at Thermo-Electron. The draft final report is under review at Sandia. Additional lens or module development contracts are being considered.

Title: PV Residential Retrofit
Contract Number: 62-0229
Directing Organization: Sandia National Laboratories
Project Engineer: J. L. Jackson
Telephone: (505) 844-7825
Contractor: Total Environmental Action
Church Hill
Harrisville, NH 03450
Principal Investigator: P. Temple
Telephone: (603) 827-3374
Contract Period of Performance: **From:** 8-11-80 **To:** 1-4-82
Project/Area/Task: Applications Analysis
Contract Funding: FY81 $275,000 FY $ FY $ FY $
Cumulative Funding To Date: $275,000

Contract objectives are to:

1. Review existing literature and characterize existing residential structures in NE, SE, & SW U.S..
2. Select representative residential structures from each region as well as appropriate PV systems for retrofitting to these structures.
3. Propose detailed retrofitting schemes and estimate resultant costs.
4. Optimize installation techniques and equipment locations. Estimate market potential.

Tasks 1-3 are completed.

Task 4 is underway.

Title:	400X Fresnel/AlGaAs Module Development
Contract Number:	42-7248
Directing Organization:	Sandia National Laboratories
Project Engineer:	J. L. Jackson
Telephone:	(505) 844-7825
Contractor:	Varian Associates 611 Hansen Way Palo Alto, CA 94363
Principal Investigator:	R. J. Owen
Telephone:	(415) 493-4000, x 4186
Contract Period of Performance:	**From:** 02-22-80 **To:** 04-22-81
Project/Area/Task:	Array Design and Fabrication
Contract Funding:	FY80 $270,000 FY $ FY $ FY $
Cumulative Funding To Date:	$270,000

Contract objectives are to:

- Design two PV prototype concentrator modules employing high concentration, curved facet, acrylic Fresnel lenses, high efficiency AlGaAs/GaAs cells and jet impingement cell cooling subsystem.
- Design goals are 14% efficiency, 20-year life and cost effectiveness.
- Develop preliminary conceptual array design employing selected module configuration.

Contract has been completed. Varian testing indicated a maximum efficiency of 17.1% at a coolant temperature of 50°C. Sandia tests indicated a maximum efficiency of 15.7% under similar conditions. SAND81-7018 sent to printer September 28, 1981.

Title:	High Efficiency, Low Cost, Passively Cooled PV Concentrator Module Development
Contract Number:	74-2999
Directing Organization:	Sandia National Laboratories
Project Engineer:	J. L. Jackson
Telephone:	(505) 844-7825
Contractor:	Varian Associates, Inc. 611 Hansen Way Palo Alto, CA 94303
Principal Investigator:	R. Owen
Telephone:	(415) 493-4000 x4186
Contract Period of Performance:	**From:** 05-11-81 **To:** 07-11-82
Project/Area/Task:	Sandia AOP Array Design & Fabrication
Contract Funding:	FY81 $320,000 FY $ FY $ FY $
Cumulative Funding To Date:	$320,000

Contract objectives are to develop two prototype concentrator modules employing passively cooled AlGaAs cells in combination with Fresnel lens and secondary concentrators. Modules will employ low cost, durable housings. One module will be shipped to Sandia for independent testing and system verification.

First phase of lens/cell/secondary concentrator study is completed. Lowest system cost/watt appears to be 7 in. square lens, 1146 x geometric concentrator ratio and f-number of 1.1.

Title:	Advanced Cover Glass for GaAs Solar Cells	**Contract Number:**	74-6832
Directing Organization:	Sandia National Laboratories		
Project Engineer:	J. J. Wiczer	**Telephone:**	(505) 844-9677
Contractor:	Varian Associates 611 Hansen Way Palo Alto, CA 94303		
Principal Investigator:	Peter Borden	**Telephone:**	(415) 493-4000 x 2614
Contract Period of Performance:	**From:** 01-15-81 **To:** 01-15-82		
Project/Area/Task:	Advanced Devices		
Contract Funding:	FY81 $104,000 FY $	FY $	FY $
Cumulative Funding To Date:	$104,000		

Contract objectives are to develop a cover glass which reduced the effect of contact obscuration by re-directing incident light away from the metallization pattern. Study and develop advanced secondary concentator designs. Work is in progress, delivery of 10 solar cells expected by January 1982.

Title:	Production Engineering of 62.5 kW Inverter	**Contract Number:**	13-5169
Directing Organization:	Sandia National Laboratories		
Project Engineer:	C. M. Coats	**Telephone:**	(505) 844-5206
Contractor:	Westinghouse AED Lima, OH		
Principal Investigator:	Wayne Niederjohn	**Telephone:**	(419) 226-3159
Contract Period of Performance:	**From:** 06-13-79 **To:** 09-07-81		
Project/Area/Task:	Power Conditioning and Control/PCS Hardware Development		
Contract Funding:	FY79 $275,344 FY80 $30,056	FY $	FY $
Cumulative Funding To Date:	$305,400		

This program is for additional design engineering and drafting necessary to convert the 50 KVA prototype PCU design developed under Contract 07-6940 into a production design rated at 62.5 KVA suitable for field use. The upgraded design will incorporate the following modifications:

- Automatic utility tie break upon loss of utility power and automatic reclosing when utility power returns.
- Modification to enable parallel operation of up to eight production PCUs.

Three units are built and in factory test at Westinghouse.

Title:	Cell Metallization Stability Research	**Contract Number:**	74-2536
Directing Organization:	Sandia National Laboratories		
Project Engineer:	Roger J. Chaffin	**Telephone:**	(505) 844-2609
Contractor:	University of Wisconsin Dept. of Electrical Engineering Madison, WI 53706		
Principal Investigator:	Prof. J. Wiley	**Telephone:**	(608) 262-9693
Contract Period of Performance:	**From:** 10-01-80 **To:** 09-31-81		
Project/Area/Task:	Advanced Devices		
Contract Funding:	FY81 $45,700 FY $	FY $	FY $
Cumulative Funding To Date:	$45,700		

Contract objective is to develop high reliability metallization processes for production of PV devices (solar cells) using amorphous metals. Normal polycrystalline metals fail at grain boundaries, amorphous metals have none. Preliminary tests indicate amorphous metals are five orders of magnitude more resistant to diffusion than are polycrystalline metals.

Effort is complete. Technology developed will now be transferred to Sandia by contract #68-5071.

Title:	Engineering Test Development Support	**Contract Number:**	49-1532
Directing Organization:	Sandia National Laboratories		
Project Engineer:	M. Rios	**Telephone:**	(505) 844-7812
Contractor:	Wyle Laboratories 7800 Governors Drive West Huntsville, AL 35807		
Principal Investigator:	George Meares	**Telephone:**	(205) 837-4411
Contract Period of Performance:	**From:** 03-19-80 **To:** 03-30-82		
Project/Area/Task:	Array Subsystem		
Contract Funding:	FY80 $119,700 FY81 $43,424	FY $	FY $
Cumulative Funding To Date:	$163,124		

The objectives of this contract are: (1) to develop and document test procedures and data analysis techniques for concentrating photovoltaic collectors in collaboration with Sandia personnel, and (2) to develop and document test procedures for power conditioning equipment in collaboration with Sandia personnel. The test procedures and data analyses for the concentrators task has been further subdivided into the following subtasks:

1-A Data Analysis Techniques

1-B PV-T Cell Temperature Determination

1-C PV-T Test Methods

1-D Data Analysis of Sandia Test Data

1-E Installation of Computer Programs on Sandia's HP 1000

The second part of the contract objectives—test procedures for power conditioning equipment—has been completed and resulted in an unpublished report on the test procedures. The unpublished report was incorporated into a more comprehensive document to be published by JPL.

A report on PV-T test procedures and multiple linear regression data analysis techniques is in preparation. A multiple linear regression for determining cell temperature is also being explored.

Jet Propulsion Laboratory

Photovoltaics Technology Development and Applications Lead Center

Title:	Analysis, Planning and Documentation Support	**Contract Number:**	955718
Directing Organization:	JPL-Photovoltaic TD&A Lead Center		
Project Engineer:		**Telephone:**	(213) 577-9415
Contractor:	Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009		
Principal Investigator:	Stan Leonard	**Telephone:**	
Contract Period of Performance:	**From:** 4/25/80 **To:** 3/30/81		
Project/Area/Task:	Planning, Analysis and Integration		
Contract Funding:	FY81 $243,007 FY $	FY $	FY $
Cumulative Funding To Date:	$243,007		

Contract objectives are to update Central Station Applications Requirement Document; assist in preparation of program documents; assist in proposal evaluations; evaluate oil conservation market; analyze utility grid and central power generation issues. Contract is complete.

Title:	Study of M-X Renewable Energy Systems	**Contract Number:**	956014
Directing Organization:	JPL-Photovoltaic TD&A Lead Center		
Project Engineer:		**Telephone:**	(213) 577-9415
Contractor:	Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009		
Principal Investigator:	S. Leonard	**Telephone:**	
Contract Period of Performance:	**From:** 3/27/81 **To:** 6/81/81		
Project/Area/Task:	Planning, Analysis and Integration		
Contract Funding:	FY81 $250,000 FY $	FY $	FY $
Cumulative Funding To Date:	$250,000		

Contract objective is to develop analytical techniques to define alternative power systems configurations for M-X missile. Contract is complete.

Title:	Study of Commercial and Residential Markets for Photovoltaic Applications	**Contract Number:**	955677
Directing Organization:	JPL-Photovoltaic TD&A Lead Center		
Project Engineer:		**Telephone:**	(213) 577-9415
Contractor:	Science Applications, Inc. 8400 Westpark Drive McLean, VA 22102		
Principal Investigator:		**Telephone:**	
Contract Period of Performance:	**From:** 12/18/80 **To:** 10/31/81		
Project/Area/Task:	FPUP		
Contract Funding:	FY81 $197,571 FY $	FY $	FY $
Cumulative Funding To Date:	$197,571		

Contract objectives are to perform commercialization study of federal grid-connected system applications and develop marketing criteria.

JPL is reviewing the final draft submitted in the fourth quarter of FY 1981.

Jet Propulsion Laboratory

Flat-Plate Solar Array Project

Title: Development of Processes for the Production of Solar Grade Silicon from Silicon Halides and Alkali Metals
Contract Number: 955491
Directing Organization: Jet Propulsion Laboratory
Project Engineer: R. Lutwack
Telephone: (213) 354-7648
Contractor: AeroChem Research Laboratories, Inc.
P.O. Box 12
Princeton, NJ 08540
Principal Investigator: Robert Gould
Telephone: (609) 921-7070
Contract Period of Performance: **From:** 10/79 **To:** 3/81
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task
Contract Funding: FY80 $225,000 FY81 $65,658 FY $ FY $
Cumulative Funding To Date: $290,658

Contract objective of Phase I is to develop processes involving high temperature reactions of silicon halides with alkali metals for the production of solar grade silicon in high volume at low cost. The objective of Phase II is to characterize the kinetics and mechanisms of the formation and growth of silicon particles from the decomposition of silane at high temperature.

Phase I is complete. The work indicates that the process is capable of producing pure silicon. Sodium levels were below 10 ppma in most tests, showing good separation of by-product sodium chloride from the product silicon. Phase II is also complete. A high temperature fast-flow reactor (HTFFR) was modified to study the decomposition of silane and the subsequent growth of particles. Experiments were carried out to determine the growth rates and absolute sizes of the particles, extent of silane decomposition, particle concentrations, and growth of seeded particles. A simplistic model was formulated to explain the growth of silicon in a decomposing silane environment.

Title: Integrated Residential PV Development
Contract Number: 955893
Directing Organization: Jet Propulsion Laboratory
Project Engineer: R. Sugimura
Telephone: (213) 577-9118
Contractor: AIA Research Corporation
1735 New York Avenue, N.W.
Washington, DC 20006
Principal Investigator: G. Royal
Telephone: (202) 626-7524
Contract Period of Performance: **From:** 11/80 **To:** 12/81
Project/Area/Task: Flat-Plate Solar Array Project; Engineering Science Area
Contract Funding: FY81 $391,288 FY $ FY $ FY $
Cumulative Funding To Date: $391,288

The contract objective is to synthesize advanced, integrated, roof-mounted flat-plate array/module concepts to identify performance drivers and technology gaps requiring long-range research. Deliverables include a laboratory mockup and a final report detailing the analyses performed and the technology gaps identified.

A laboratory mockup of the selected concept, using 2 ft x 8 ft gasketless modules adhesively bonded to cedar rails, was displayed at the 19th FSA PIM. A draft final report is scheduled for JPL review in January 1982.

Title:	Design, Fabrication, Testing, and Price Analysis of "Third Generation" Design Solar Cell Modules	**Contract Number:**	955409
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	M. Smokler	**Telephone:**	(213) 577-9238
Contractor:	Applied Solar Energy Corporation 15251 Don Julian Road City of Industry, CA 91746		
Principal Investigator:	K. Ling	**Telephone:**	(213) 968-6581
Contract Period of Performance:	**From:** 5/79 **To:** 1/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY79 $65,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$65,000		

Contract objectives are to design, fabricate, test, and deliver pre-production solar cell modules which comply with requirements of JPL Document 5101-16 Rev. A, entitled, "Block IV Solar Cell Modules Design and Test Specification for Intermediate Load Center Applications." Prepare also a standardized price estimate for 10, 100, 1000 kW of modules delivered in 1980.

All contractually required supplies and services have been provided and the contract is completed. These include (1) a Preliminary Design Review, (2) delivery of eleven pre-production modules, (3) a Final Design Review, documentation including (a) Program Plan, (b) Monthly Technical Progress Reports, (c) Design Review Data Packages, (d) Engineering and Manufacturing Documentation, (e) Inspection System Plans, (f) Final Design Report, (g) SAMICS/SAMIS Price Estimate, and (h) Delivery Data Packages. The module design developed under this contract met the requirements of the Block IV specification which at the time of issue imposed more stringent demands upon the performance and durability of modules than previously issued requirements.

Title:	Laboratory Services	**Contract Number:**	955423
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	D. Burger	**Telephone:**	(213) 577-9374
Contractor:	Applied Solar Energy Corporation 15251 E. Don Julian Blvd. City of Industry, CA 91746		
Principal Investigator:	K. Ling	**Telephone:**	(213) 968-6581
Contract Period of Performance:	**From:** 3/79 **To:** 9/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY79 $135,000 FY80 $-0- FY81 $75,000 FY $		
Cumulative Funding To Date:	$210,000		

Contract objective is to provide laboratory services to perform solar cell and solar module manufacturing process steps and testing as directed by JPL.

Contractor has performed satisfactorily in support of many research programs. Major efforts have been: support of process verification efforts; AR coating research; and Fritless ink research support.

Title:	Solar Cell Process Development	**Contract Number:**	955089
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	S. Hyland	**Telephone:**	(213) 354-2190
Contractor:	Applied Solar Energy Corp. 15251 E. Don Julian Road City of Industry, CA 91746		
Principal Investigator:	D. Leung	**Telephone:**	(213) 968-6581
Contract Period of Performance:	**From:** 5/78 **To:** 1/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY77 $223,920 FY78 $113,000 FY79 $302,572 FY80 $250,049		
Contract Funding:	FY81 $ 33		
Cumulative Funding To Date:	889,574		

Contract objectives include fabrication of solar cells using reliable and reproducible processes; testing of the solar cells using standardized equipment and techniques; investigate, develop, and utilize technologies appropriate and necessary for improving the efficiency of solar cells made from large area silicon sheets.

This contract is presently in Phase III which stresses the optimization of processing to maximize the efficiency of the solar cells from unconventional silicon sheets.

During Phase III, baseline cells were made on HEM material and Semix UCP material in order to map the quality of these materials over an entire ingot. Fabrication of cells from EFG ribbons grown with and without CO_2 atmosphere gave conflicting results.

Cells were fabricated on LASS horizontal and EFG ribbons, SEMIX UCP material, and HEM material, using more sophisticated processing, yielding AM1 efficiencies of 11.8% for LASS, 13.8% for EFG, 13.2% for UCP, and 16% for HEM.

Phase IV (beginning December 10, 1981) will stress the use of "baseline" processing as applied to large area cells from unconventional silicon sheets. Work will continue on optimization of processing for small area cells.

Title:	Development of High Efficiency (14%) Solar Cell Array Module	**Contract Number:**	955217
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	J. Behm	**Telephone:**	(213) 577-9563
Contractor:	Applied Solar Energy Corporation 15251 E. Don Julian Road City of Industry, CA 91746		
Principal Investigator:	K. Ling	**Telephone:**	(213) 968-6581
Contract Period of Performance:	**From:** 11/79 **To:** 3/31		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY79 \$164,000 FY80 \$30,576 FY \$ FY \$		
Cumulative Funding To Date:	\$194,576		

Contract objectives include designing a solar array module using high efficiency (16%) Air Mass 1 (AM1) solar cells; approximately 48 in. in length, 23 in. in width and the thickness as appropriate; each module to produce at least 90 watts of peak power at 20°C with an overall operating efficiency greater than or equal to 14%; and designed to achieve the lowest possible operating temperature, consistent with the high efficiency requirement.

The final report distribution was completed in January 1981.

Major accomplishments:

1. Developed a completely new, large area (3 in. diameter), high efficiency P^+NN^+ solar cell with cell of 13.5%.
2. Developed new tooling for cell-interconnect soldering for fabrication if solar modules approximately 2 x 4 ft in size. This tooling design has since been upgraded and semiautomated by the contractor under his own funds to reduce production costs and improve reliability.

Title: Automated Solar Panel Assembly Line | **Contract Number:** 955278
Directing Organization: Jet Propulsion Laboratory
Project Engineer: J. Behm | **Telephone:** (213) 577-9563
Contractor: ARCO Solar, Inc.
20554 Plummer St.
Chatsworth, CA 91311
Principal Investigator: R. Keenan | **Telephone:**
Contract Period of Performance: **From:** 1/79 **To:** 4/81
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY79 $383,000 FY80 $90,275 FY $ FY $
Cumulative Funding To Date: $473,275

Contract objective is to design, fabricate, develop, and demonstrate an automated solar module assembly production line. The objective is to significantly reduce the price of current commercial flat-plate photovoltaic modules available in the marketplace.

The final automated demonstration production run was completed successfully on April 10, 1981. A total of 288 modules were fabricated of which 56 were delivered to JPL.

Initial qualification testing of 5 modules was completed at JPL in August 1981. Field testing of 32 more modules are planned at 4 different test sites starting early in 1982.

A preliminary SAMIS cost projection analysis has been completed and reviewed at JPL. This analysis is expected to be finalized in February 1982.

The final draft report has been reviewed at JPL and recommended revisions have been identified. Release date of the final report is targeted for February 1982.

Title: Vacuum Die Cast of Silicon Sheet for Photovoltaic Applications | **Contract Number:** 955325
Directing Organization: Jet Propulsion Laboratory
Project Engineer: A. Morrison | **Telephone:** (213) 354-7200
Contractor: ARCO Solar, Inc.
20554 Plummer St.
Chatsworth, CA 91311
Principal Investigator: — | **Telephone:**
Contract Period of Performance: **From:** 3/79 **To:** 10/80
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY79 $240,000 FY $ FY $ FY $
Cumulative Funding To Date: $240,000

Contract objectives are to develop a vacuum die-casting process for producing silicon sheet suitable for photovoltaic cells, to scale up the vacuum die-casting process for producing silicon sheet suitable for commercial scale production, and to develop production techniques for optimization of polycrystalline silicon solar cell output.

None of the above objectives were achieved. No final report will be issued. This program was terminated in the first quarter of FY 1981.

Title:	Design, Fabrication, Test, Qualification and Price Analysis of "Third Generation" Design Solar Cell Modules	**Contract Number:**	955402
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	R. Greenwood	**Telephone:**	(213) 577-9290
Contractor:	ARCO Solar, Inc. 20554 Plummer St. Chatsworth, CA 91311		
Principal Investigator:	W. Bottenberg	**Telephone:**	(213) 700-7163
Contract Period of Performance:	**From:** 7/79 **To:** 5/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY80 $280,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$280,000		

Contract objectives are to design, fabricate, test, qualify, and deliver intermediate load pre-production solar cell modules and residential load pre-production solar cell modules. Prepare a standardized price estimate with supporting analyses and input data for the approved module design for each of the two types of modules, using the Solar Array Manufacturing Industry Costing Standards (SAMICS) and the Solar Array Manufacturing Industry Simulation (SAMIS) computer program.

ARCO intermediate load modules met the requirements of the contract after a module design change was implemented. The final design review for the intermediate load module was held September 16, 1981. All documentation including the SAMICS/SAMIS price estimates for the intermediate load modules has been delivered and accepted.

ARCO residential modules have been submitted following a minor design change to improve lamination integrity. The modules are currently in environmental testing at JPL. The final report, due in the second quarter of FY 1982, will cover both the IL module and the residential module designs.

Title:	Design of Block V Solar Cell Modules—1981	**Contract Number:**	956097
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	M. Smokler	**Telephone:**	(213) 577-9238
Contractor:	ARCO Solar, Inc. 20554 Plummer St. Chatsworth, CA 91311		
Principal Investigator:	G. Cherniak	**Telephone:**	(213) 700-7162
Contract Period of Performance:	**From:** 8/81 **To:** 1/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY81 $25,721 FY $ FY $ FY $		
Cumulative Funding To Date:	$25,721		

Contract objective is to design intermediate load solar cell modules to incorporate such new features from the project work or other sources that lead to lower unit module cost, higher module efficiency or improvement of other factors commensurate with meeting project price and production goals. (Block V Solar Cell Module Design and Test Specifications for Intermediate Load Applications—1981—JPL Document 5106-161.)

Design concept is defined. Drawings and inspection system plan are in preparation, but behind schedule so the design review, due in the second quarter of FY 1982, will be about two weeks late.

Title:	Part 1—Evaluation of Silicon Production Suitable for Solar Cells
Contract Number:	954339
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	R. Lutwack
Telephone:	(213) 354-7648
Contractor:	Battelle Memorial Institute Columbus Laboratories 5050 King Avenue Columbus, OH 43201
Principal Investigator:	M. F. Browning
Telephone:	(614) 424-7460
Contract Period of Performance:	**From:** 10/75 **To:** 10/81
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Project Silicon Material Task
Contract Funding:	FY76 $279,999 FY77 $493,758 FY78 $502,000 FY79 $560,000
Contract Funding:	FY80 $621,666
Cumulative Funding To Date:	$2,457,423

Contract objective includes a study and development of processes, the goal being the establishment of the feasibility of a process capable of producing silicon suitable for solar cells in high volume quantities at a cost less than $14/kg (1980 $).

The bulk of the Battelle effort was devoted to investigating and evaluating the technical and economic feasibility of the zinc vapor reduction of silicon tetrachloride in a fluidized bed of silicon seed particles as a means of producing high-purity silicon granules. This process was selected on the basis of an evaluation of six candidate processes, one employing silicon tetrachloride and five based on either thermal decomposition or hydrogen reduction of silicon tetraiodide. Preliminary economic analysis indicates that the process can produce silicon at a price as low as $14.80/kg (1980 $, 20% ROI, 1000 MT/yr plant).

With delivery of the Conceptual Analysis Report this contract will be complete. The analysis is of an improved design developed from a critique of the PDU (process development unit) design and of the Battelle process for producing low-cost, solar-cell-grade silicon.

Title:	Development of an All Metal Thick Film Cost Effective Metallization System for Solar Cells	**Contract Number:**	954688
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	B. Gallagher	**Telephone:**	(213) 577-9255
Contractor:	Bernd Ross Associates 2154 Blackmore Court San Diego, CA 92109		
Principal Investigator:	B. Ross	**Telephone:**	(714) 274-1391
Contract Period of Performance:	**From:** 5/80 **To:** 8/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY80 $113,716 FY81 $20,000 FY $ FY $		
Cumulative Funding To Date:	$133,716		

Contract objectives are to develop and perform expert analysis and critical evaluation of an all metal improved thick film solar cell contact utilizing base metals.

All metal copper based back contacts have been successfully formulated which have produced solar cells with efficiencies greater than 13%. Original reproducibility problems with formulating the thick film inks have been solved. Current investigations involve the analysis of the possible kinetic reactions occurring at the silicon surface as a function of metal composition, firing schedules, and ambients.

Title:	Solar Dome Encapsulation and Array Wind Loading Study	**Contract Number:**	954833
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	R. Weaver	**Telephone:**	(213) 354-4984
Contractor:	The Boeing Company P.O. Box 3707 Seattle, WA 98124		
Principal Investigator:	D. Zimmerman	**Telephone:**	(206) 575-5739
Contract Period of Performance:	**From:** 8/77 **To:** 11/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Engineering Sciences Area		
Contract Funding:	FY77 $97,919 FY78 $115,301 FY79 $20,000 FY80 $111,990		
Contract Funding:	FY81 $30,672		
Cumulative Funding To Date:	$375,882		

The contract was carried out in four phases. Phase I. Define and assess the potential technical and economic benefits obtained when solar photovoltaic arrays are protected by the air-supported structures. Phase II. Analytically determine wind loads on PV arrays both in fields of arrays and individually. Phase III. Conduct wind tunnel tests to determine wind loads on arrays for design purposes. Phase IV. Determine the structural dynamics of various support structures and, using the wind tunnel data from Phase III, determine the dynamic response of the structures.

All phases of the contract have been completed and deliverables have been received and published.

Phase I of the study found that air supported enclosures have important economic benefits chiefly associated with lowering support structure costs which are driven by wind loading requirements. To judge the relative merits of air supported enclosures, it was necessary to better define the actual loading levels and requirements for conventional frame structures. The subsequent phases of the contract developed detailed parametric data based on both analysis and wind tunnel testing and documented the results in a design handbook format useful to array designers. Wind loading levels were shown to be much lower than previously thought.

Title:	Commercial/Industrial Photovoltaic Modules Requirements Study
Contract Number:	955698
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	R. Sugimura
Telephone:	(213) 577-9118
Contractor:	Burt Hill Kosar Rittelmann Associates 400 Morgan Center Butler, PA 16001
Principal Investigator:	J. Oster
Telephone:	(412) 285-4761
Contract Period of Performance:	**From:** 4/80 **To:** 3/81
Project/Area/Task:	Flat-Plate Solar Array Project; Engineering Sciences Area
Contract Funding:	FY80 $115,354 FY $ FY $ FY $
Cumulative Funding To Date:	$115,354

The contract objective is to conduct a study to identify the design requirements for photovoltaic modules and arrays applicable to commercial/industrial installations, and provide a final report. The work shall reflect projected 1986 photovoltaic module technology and current building codes and construction practices.

The draft final has been reviewed by JPL and distribution is expected in January 1982. The report begins with a summary of the building process sequence, and examines some critical "realities of the building industry." The Model Building Codes are examined in detail, both from the viewpoint of fire resistance ratings of building materials and the structural integrity of building component assemblies. Consistent with existing practices structural/mechanical requirements are examined in terms of modularity with the conclusion that modules/panels should be based on some multiple of 4 ft x 5 ft, nominal.

The general conclusion is that there are no significant obstacles to the use of photovoltaic arrays in the commercial/industrial sector. However, since there is no applicable building code category for photovoltaic modules and arrays, it is recommended that the design and application of photovoltaic modules be limited to a single function (generating electrical power) and not considered a building product also.

Title:	An Exploratory Study of Product Safety and Product Liability Considerations for Photovoltaic Module/Array Devices	**Contract Number:**	955846
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	E. Royal	**Telephone:**	(213) 577-9580
Contractor:	Carnegie Mellon University Department of Mechanical Engineering Schenley Park Pittsburgh, PA 15213		
Principal Investigator:	A. Weinstein/D. Meeker	**Telephone:**	(412) 478-2509
Contract Period of Performance:	**From:** 8/80 **To:** 8/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Engineering Sciences Area		
Contract Funding:	FY80 $14,423 FY81 $2,437 FY $ FY $		
Cumulative Funding To Date:	$16,860		

Contract objectives are to conduct an exploratory study and provide explicit considerations and recommendations relative to product safety on future solar photovoltaic module/array device designs. Another objective is to develop a manual/workbook to assess safety/product liability guidelines for PV flat-plate module/array designs and conduct two case studies to assess safety design review procedures followed, hazards, and potential for product liability litigation.

Final report is completed and distributed. Contract is concluded.

The final report contains an exploratory survey of the areas of concern, the generic types of hazards that can arise, the methodologies for analysis, and the types of alternatives that can be devised to enhance safety and reduce liability in the use of photovoltaic energy sources. Scenarios postulated in this report are foreseeable, and it attempts to show that the appropriate time to interweave concerns for safety, reliability, and performance is during the development phase of a new technology.

Title: Encapsulation System Studies for Low-Cost Silicon Solar Array
Contract Number: 954738
Directing Organization: Jet Propulsion Laboratory
Project Engineer: Jovan Moacanin
Telephone: (213) 354-3178
Contractor: Case Western Reserve University
2040 Adelbert Road
Cleveland, OH 44106
Principal Investigator: Charles Rogers
Telephone: (216) 368-4175
Contract Period of Performance: **From:** 3/77 **To:** 10/81
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task

Contract Funding: FY77 $25,000 FY78 $25,000 FY79 $26,290 FY80 $42,000
Contract Funding: FY81 $33,000
Cumulative Funding To Date: $151,290

Contract objective is to conduct a study program to determine the dependence of sorption, diffusion, and permeability of water and environmental gases on the nature and extent of photodegradation of polymers.

The present work nas established the modes of degradation of poly (n-butylacrylate) (PNBA) and the relationships between selected chemical changes and physical properties. The objective of these current studies is to predict long-term physical changes from the short-term accelerated environmental exposures and measurements of chemical changes.

Title: Investigation of Reliability Attributes and Accelerated Stress Factors on Terrestrial Solar Cells
Contract Number: 954929
Directing Organization: Jet Propulsion Laboratory
Project Engineer: E. Royal
Telephone: (213) 577-9580
Contractor: Clemson University
College of Engineering
Clemson, SC 29631
Principal Investigator: J. Lathrop
Telephone: (803) 656-3371
Contract Period of Performance: **From:** 12/77 **To:** 9/82
Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area
Contract Funding: FY78 $123,649 FY79 $110,534 FY80 $81,308 FY81 $105,134
Cumulative Funding To Date: $420,625

The contractor shall perform research investigations of factors involved in the reliability of terrestrial solar cells and develop a suitable approach for accelerated stress testing of solar cells. The contractor shall also utilize failure analysis methods to ascertain the causes of failure. This shall be performed in conjunction with research within the Engineering Sciences Area at JPL.

New expanded research effort started to explore the reliability attributes of encapsulated photovoltaic cells compared with those of nonencapsulated cells. A small pilot research effort was started to develop means to make test specimens of individual photovoltaic cells that are encapsulated and edge sealed. Initial result to be available by March 1982.

Title:	Investigation of Physical Structure and the Chemical Nature of Defects in the Silicon Sheet Material	**Contract Number:**	956046
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	L. Cheng	**Telephone:**	(213) 354-3068
Contractor:	Cornell University P.O. Box DH Ithaca, NY 14853		
Principal Investigator:	Dr. D. Ast	**Telephone:**	(415) 857-1501
Contract Period of Performance:	**From:** 6/22/81 **To:** 5/15/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY81 $20,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$20,000		

Contract objective is to extend understanding of the structural, electrical, and chemical nature of silicon sheet material. Primary emphasis is on correlation of the structural, electrical, and chemical properties of silicon sheet material leading to a better understanding of their potential to produce high efficiency solar cells.

The main effort since the beginning of the contract has been concentrated on structural defects in processed EFG materials. It has been found that precipitates containing high concentration of carbon (~1-3 μm in diameter) are formed in the EFG materials. The precipitates seem to act as impurity gettering centers. The work will be extended to include investigation on processed web and HEM materials.

Title:	Characterization of Structural, Electrical, and Chemical Properties of Silicon Sheet Material	**Contract Number:**	954852
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	L. Cheng	**Telephone:**	(213) 354-3068
Contractor:	Cornell University Ithaca, NY 14853		
Principal Investigator:	Dr. D. Ast	**Telephone:**	(415) 856-1501
Contract Period of Performance:	**From:** 3/78 **To:** 11/78		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY79 $90,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$90,000		

Contract objective is to perform basic research leading to the understanding of structural, electrical, and chemical nature of silicon sheet material. The efforts are to be directed towards correlating the structural, electrical, and chemical properties of silicon sheet material leading to the better understanding of their potential to produce high efficiency solar cells.

The contractor work made significant progress toward the understanding of structural defects in LSA Project new materials and their effects on solar cell performance. The results show that the most prominent defect in Web, EFG, HEM, RTR, and SOC silicon sheet materials are coherent twins. The perfect coherent twins did not act as minority carrier recombination centers. However, coherent twins can contain structural defects in themselves. These defects tend to act as recombination centers and decrease the efficiency of solar cells. The second most prominent defect in these new materials is dislocation. In general, dislocations in silicon are relatively weak recombination centers. Glide induced dislocations are much more strongly active. It is found that the latter can be passivated very effectively by atomic hydrogen.

Final report was approved for distribution in May 1981.

Title:	Heat Exhanger-Ingot Casting/ Slicing Process, Silicon Sheet Growth Development	**Contract Number:**	954373
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	K. Dumas	**Telephone:**	(213) 354-6546
Contractor:	Crystal Systems, Inc. 35 Congress Street Salem, MA 01970		
Principal Investigator:	F. Schmid	**Telephone:**	(617) 745-0088
Contract Period of Performance:	**From:** 3/77 **To:** 6/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		

Contract Funding:	FY76 $208,393	FY77 $427,408	FY78 $499,832	FY79 $273,854
Contract Funding:	FY80 $687,345	FY81 $364,193		
Cumulative Funding To Date:	$2,460,972			

Contract objective is to produce large areas of silicon sheet material by the heat exchanger-ingot casting/slicing process suitable for use as solar cells.

HEM Program

35-kg ingots (dimensions approximately 30 x 30 x 15 cm) were grown in less than a 48 hour cycle time. Electrical characterization studies showed that the average efficiency of all usable material in the ingot was 85% of simultaneously processed Cz control cells. After completion of the contract goals, the HEM Program was no longer supported.

FAST Program

The ability to slice 25 wafers/cm of 10-cm diameter ingots was demonstrated. Although the yields are low, the FAST saw is able to slice 15-cm diameter ingots. Work on this program is continuing under Contract #956043.

Draft of final report for the HEM Program has been reviewed by JPL and returned to contractor for distribution.

Final report for the FAST Program is expected in the second quarter of FY 1982.

Title:	Multi-Wire Wafering Technology Development by a Fixed Abrasive Slicing Technique (FAST) — **Contract Number:** 956073
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	K. Dumas — **Telephone:** (213) 354-6546
Contractor:	Crystal Systems, Inc. 35 Congress Street Salem, MA 01970
Principal Investigator:	F. Schmid — **Telephone:** (617) 745-0088
Contract Period of Performance:	**From:** 7/81 **To:** 11/81
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task
Contract Funding:	FY81 $80,000 FY $ FY $ FY $
Cumulative Funding To Date:	$80,000

Contract objectives are to produce silicon wafers suitable for use as solar cells sliced by the Fixed Abrasive Slicing Technique (FAST) and to perform a series of experiments to demonstrate state of the art in FAST wafering and provide written reports.

Slicing of 10-cm diameter ingots at 25 wafers/cm (the goal) has been routinely achieved. The cutting rate standardly is approximately 0.07 mm/min which is 70% of the goal. Problem areas of erratic yields and low wirelife still exist. Work is also continuing on the means to slice 15-cm diameter ingots.

Title:	Gaseous Melt Replenishment System — **Contract Number:** 955269
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	P. Seshan — **Telephone:** (213) 354-7215
Contractor:	Energy Materials Corporation Ayers Road Harvard, MA 01451
Principal Investigator:	D. Jewett — **Telephone:** (617) 456-8707
Contract Period of Performance:	**From:** 4/79 **To:** 10/80
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding:	FY80 $329,002 FY $ FY $ FY $
Cumulative Funding To Date:	$329,002

Contract objectives are to develop and demonstrate a melt replenishment system to cope with advanced Czochralski practice to be carried out and repeated in a cyclic mode to provide molten silicon in the quantities at the rates specified for continuous Czochralski crystal growth.

The reactor was constructed and operated. The demonstrated production rate was only 0.25 kg/hr of silicon. However, conversion efficiencies greater than 18 mole percent were achieved. Since the effort will not be extended the program objective of a durable, continuously operating melt replenishment system was not realized.

The final report was received and distributed in the first quarter of FY 1981.

Title:	Integrated Residential Photovoltaic Array Development
Contract Number:	955894
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	R. Sugimura
Telephone:	(213) 577-9118
Contractor:	General Electric Corporation Valley Forge Space Center P.O. Box 8661 Philadelphia, PA 19101
Principal Investigator:	N. Shepard
Telephone:	(215) 962-5839
Contract Period of Performance:	**From:** 10/80 **To:** 11/81
Project/Area/Task:	Flat-Plate Solar Array Project; Engineering Sciences Area
Contract Funding:	FY80 $100,000 FY81 $195,835 FY $ FY $
Cumulative Funding To Date:	$295,835

Contract objective is to synthesize advanced, integrated, roof-mounted flat-plate array/module concepts to identify performance drivers and technology gaps requiring long-range research. Deliverables include a laboratory mock-up and a final report detailing the analyses performed and the technology gaps identified.

A six-module, mock-up roof section, using 2 ft x 4 ft modules and incorporating all the features of the selected array concept, was displayed at the 19th FSA PIM. Draft final reports on the integrated photovoltaic array research and an add-on task involving the integration of by-pass diodes into the module encapsulation system are scheduled for JPL review in January 1982.

Title:	Design of Block V Solar Cell Module - 1981
Contract Number:	956098
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	M. Smokler
Telephone:	(213) 577-9238
Contractor:	General Electric Company Advanced Energy Programs Department P.O. Box 8661 Philadelphia, PA 19101
Principal Investigator:	N. Shepard
Telephone:	(215) 962-5839
Contract Period of Performance:	**From:** 8/81 **To:** 11/81
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area
Contract Funding:	FY81 $74,000 FY $ FY $ FY $
Cumulative Funding To Date:	$74,000

Contract objective is to design residential load solar cell modules designed to incorporate such new features from the project work or other sources that lead to lower unit module cost, higher module efficiency or improvement of other factors commensurate with meeting the project price and production goals. (Block V Solar Cell Module Design and Test Specifications for Residential Applications—1981—Document 5101-162.)

All contractually required supplies and services have been provided on schedule in the first quarter of FY 1982. These include (1) a Preliminary Design Review, (2) Documentation including (a) Monthly Letter Technical Report, (b) Design Review Data Package, (c) Preliminary Engineering and Manufacturing Documentation and (d) Preliminary Inspection System Plan and (3) attendance at FSA PIMs. The module design presented was responsive to the requirement of the Block V specification which demands more severe environmental testing, and attention to safety, and fault tolerance that have not been required by previous specifications issued by JPL.

Title:	Development of a Polysilicon Process Based on Chemical Vapor Deposition	**Contract Number:**	955533
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Briglio	**Telephone:**	(213) 354-4883
Contractor:	Hemlock Semiconductor Corporation 12334 Geddes Road Hemlock, MI 48626		
Principal Investigator:	F. Plahutnik	**Telephone:**	(517) 624-5201
Contract Period of Performance:	**From:** 10/79 **To:** 7/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task		
Contract Funding:	FY80 $783,000 FY81 $727,000 FY $ FY $		
Cumulative Funding To Date:	$1,510,000		

The contractor shall conduct detailed studies, testing, and associated efforts to develop a low-cost process for producing polysilicon approaching semiconductor-grade quality by chemical vapor deposition from dichlorosilane (DCS) and/or mixture of dichlorosilane and trichlorosilane (TCS).

In reactor tests, the conversion efficiency and deposition rate goals required to meet program objectives are being achieved, but not simultaneously. The reactor power consumption is considerably lower for DCS than for TCS but is still higher than the goal. The deposition rate of silicon on the inside wall of the reactor is higher than desired, but steps to reduce or eliminate this problem are planned.

The catalytic conversion of TCS to DCS was investigated in a laboratory-seale apparatus, and a process development unit (PDU) was designed, constructed, and put into operation to study this conversion on a larger scale and to supply the DCS needed for reactor tests. The PDU (incorporating design changes resulting from safety-related tests on DCS) integrated with Si deposition reactors is operating successfully.

A stop work order was issued August 11, 1981, covering detailed design of an experimental process system development unit (EPSDU) and evaluation of design and economic analysis of a 1000-MT/yr silicon production plant because of budget limitations.

A preliminary economic analysis for a 1000-MT/yr plant was performed, indicating a product price of $19.23/kg (1980 $, 20% ROI).

Title:	Multiple-Blade Sawing (MBS) of Silicon Ingot into Sheet	**Contract Number:**	955981
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Morrison	**Telephone:**	(213) 354-7200
Contractor:	P. R. Hoffman Company Division of Norlin Industries 321 Cherry Street Carlisle, PA 17013		
Principal Investigator:	J. Ross	**Telephone:**	(717) 243-2011
Contract Period of Performance:	**From:** 3/81 **To:** 5/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY80 $150,000 FY81 $1,484	FY $	FY $
Cumulative Funding To Date:	$151,484		

Contract objective is to develop a low-cost material-efficient Multiple-Blade Sawing (MBS) technology capable of producing silicon wafers suitable for use as low-cost solar cells which achieve project goals. These goals are defined as wafering of ingots of up to 150-mm diameter with conversion ratio of 1 m^2/kg, wafering process value added of less than $14/$m^2$ (1980$), cutting rate of approximately 1/2 wafer/min and a 95% yield. These goals are to be demonstrated in two phases.

Design and fabrication of a wafer lift-off mechanism will be completed by the end of the first quarter of FY 1982. Alternate slurry vehicles have been evaluated and some cost saving realized. Centrifugation, filtration, and cyclonic separation have been studied for slurry reclamation. Cyclonic separation appears feasible and will be further evaluated. The use of force monitoring, contoured blades, and work-piece rocking have been shown to improve cutting throughput.

Title: Dip Coating Process, Silicon Sheet Growth Development
Contract Number: 954356
Directing Organization: Jet Propulsion Laboratory
Project Engineer: T. Daud
Telephone: (213) 354-5782
Contractor: Honeywell, Inc.
Corporate Research Center
10701 Lyndale Avenue
Bloomington, MN 55420
Principal Investigator: D. Zook
Telephone: (612) 887-4383
Contract Period of Performance: **From:** 10/75 **To:** 12/80
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task
Contract Funding: FY76 $193,229 FY77 $480,555 FY78 $400,000 FY79 $478,112
Contract Funding: FY80 $569,999 FY81 $37,108
Cumulative Funding To Date: $2,159,003

Contract objective is to determine the feasibility of silicon films on ceramic (SOC) as a means of producing large areas of silicon sheet for use as photovoltaics in terrestrial power generating systems.

Continuous coating of silicon on nonslotted mullite-substrates was demonstrated on SCIMII for 10-cm wide substrates at coating speeds of up to 30 cm/min. (Project goal was 12.5 cm x 15 cm/min.) The silicon coatings are fairly uniform but very thin (less than 10 μm against a project goal of 100 μm).

A few coatings at low speeds (3-5 cm/min) resulted in thicker (>50 μm) silicon. Dip coating process was operational for cell fabrication effort but the efficiencies of AR coated cells continued to be around 10% (against an FSA goal of 11% encapsulated cell efficiency), with a maximum of 10.5%.

The SOC program work at JPL for the FSA Project was transferred to SERI in January 1981. Final report has now been sent to JPL and the contract is closed.

Title: Demonstration of Capability to Metallize Solar Cells by Ion-Plating
Contract Number: 955506
Directing Organization: Jet Propulsion Laboratory
Project Engineer: E. Cuddihy
Telephone: (213) 354-3188
Contractor: Illinois Tool Works, Inc.
1427 Holmes Road
Elgin, IL 60120
Principal Investigator: W. Conley
Telephone: (312) 741-6800
Contract Period of Performance: **From:** 12/79 **To:** 5/82
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task
Contract Funding: FY80 $120,000 FY81 $100,000 FY $ FY $
Cumulative Funding To Date: $220,000

Contract objectives are to investigate, achieve, and demonstrate the capability to produce operational solar cells having front and back metallizations and antireflective (AR) coatings, both deposited by the use and techniques of pure, gasless, ion-plating.

Demonstrated routine capability to metallize P-on-N Solar Cells, and the N front surface of N-on-P solar cells by ion-plating, without the need of a firing step. Has demonstrated that ion-plating can metallize the P back surface of N-on-P cells without firing, but not yet on a routine basis. Cause of this limitation is under investigation.

Title:	Study of the Abrasive Wear Rate of Silicon — **Contract Number:** 956053
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	S. Hyland — **Telephone:** (213) 354-2190
Contractor:	The Board of Trustees of the Univ. of Illinois For Chicago Circle Campus Box 4348 Chicago, IL 60680
Principal Investigator:	Steve Danyluk — **Telephone:** (312) 996-2437
Contract Period of Performance:	**From:** 6/18/81 **To:** 7/01/82
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task
Contract Funding:	FY81 $16,489 FY $ FY $ FY $
Cumulative Funding To Date:	$16,489

The contractor shall perform a study to investigate surface "softening" effects and comparative abrasive wear rates of silicon by varying the coolant (N-Alcohol) in contact with the workpiece (a silicon wafer), the light intensity falling on the workpiece, and the temperature of the workpiece.

In the course of this contract, it has been determined that there is a mechanism which causes the surface "softening" of silicon in the presence of n-alcohols. The amount of "softening" of the surface is determined by measuring the depth of a groove scratched by a pyramid diamond into the silicon in the presence of the n-alcohol. It varies inversely with the dielectric constant of the liquid, i.e., an alcohol with a dielectric constant lower than that of water will "soften" the surface more than water. The amount of "softening" is also proportional to the percentage of n-alcohol in the liquid; i.e., a mixture of 50% acetone with 50% water, will allow cutting at a rate half-way between that in a 100% water atmosphere and that in a 100% acetone atmosphere.

Title:	Technical Support in Reliability Engineering of Photovoltaic Modules — **Contract Number:** 955720
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	E. Royal — **Telephone:** (213) 577-9580
Contractor:	IIT Research Institute 10 West 35th Street Chicago, IL 60616
Principal Investigator:	P. Mihalkanin — **Telephone:** (312) 567-4511
Contract Period of Performance:	**From:** 3/80 **To:** 12/81
Project/Area/Task:	Flat-Plate Solar Array Project; Engineering Sciences Area
Contract Funding:	FY80 $73,747 FY81 $60,000 FY $ FY $
Cumulative Funding To Date:	$133,747

Contract objective is to develop reliability analysis research methods suitable for use on flat-plate photovoltaic array/module designs.

Draft final report rescheduled for February 1982. This report will be finalized and released approximately one month later in March 1982.

Title:	Advanced CZ Growth Process	**Contract Number:**	955733
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Morrison	**Telephone:**	(213) 354-7200
Contractor:	Kayex Corporation 1000 Millstead Way Rochester, NY 14624		
Principal Investigator:	R. Lane	**Telephone:**	(716) 235-2524
Contract Period of Performance:	**From:** 9/80 **To:** 5/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY80 $153,440 FY81 $508,479 FY $ FY $		
Cumulative Funding To Date:	$661,919		

Contract objective is to develop a continuous Czochralski growth process capable of producing silicon suitable for use as low-cost solar cells. The cost goal is less than $799 (1980$) per peak kilowatt by 1986. The goals of this program are: continuous growth of 150 kg or more of multiple ingots, each of approximately 30 kg in weight, from one common crucible with melt-replenishment; resistivity of 1 to 3 ohm-cm; p-type, in all crystals; dislocation density below 10^4 per cm^2; diameter of 15 cm for each ingot, growth throughput greater than 2.5 kg per hour of machine operation; orientation: (100); after growth yield of greater than 90%, and prototype equipment suitable for high volume silicon production transferable directly to industry.

Although a demonstration of state of the art will be performed, a redirection of the statement of work to fit the administration guidelines has reduced the priority of the demonstration in order to emphasize more basic R&D. Automation of the growth process is virtually complete and very successful. Study of silicon/silica reaction and of use of heat shield to accelerate melt down and growth will occupy the remainder of the contract effort.

Title:	Development of Advanced Methods for Continuous CZ Growth	**Contract Number:**	954888
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Morrison	**Telephone:**	(213) 354-7200
Contractor:	Kayex Corporation - Hamco Division 1000 Milstead Way Rochester, NY 14624		
Principal Investigator:	R. Lane	**Telephone:**	(716) 235-2524
Contract Period of Performance:	**From:** 12/77 **To:** 12/80		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY78 $270,000 FY79 $246,892 FY80 $197,379 FY $		
Cumulative Funding To Date:	$714,271		

Contract objective is to develop methods of demonstrating continuous Czochralski growth. Continuous growth is defined as a throughput of silicon that produces 100 kg of silicon single crystal(s) material of 10 cm in diameter or greater, using one common silicon container material (one crucible).

All of the goals of this contract were achieved with the exception of throughput (2.1 kg/hr vs. 2.5 kg/hr goal). A new CPFF completion type contract with TR demonstration (150 kg of ingots, 15 cm in diameter, from a single crucible, capable of achieving 15% average AM1 photovoltaic conversion efficiency, 2.5 kg/hr throughput rate) was signed October 1980.

Final report was printed and distributed in the first quarter of FY 1982.

Title: Low Cost Czochralski Crystal Growing Technology
Contract Number: 955270
Directing Organization: Jet Propulsion Laboratory
Project Engineer: R. Kachare
Telephone: (213) 354-4583
Contractor: Kayex Corporation
1000 Milstead Way
Rochester, NY 14624
Principal Investigator: R. Lane
Telephone: (716) 235-2524
Contract Period of Performance: **From:** 3/79 **To:** 10/81
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector; Large Area Silicon Sheet Task
Contract Funding: FY79 $250,000 FY80 $257,990 FY $ FY $
Cumulative Funding To Date: $507,990

Contract objectives include to develop and demonstrate continuous Czochralski growth technology. This growth is defined as a throughput greater than 150 kg of silicon crystal material of 15 cm in diameter, using one common crucible.

The feasibility of a cold crucible levitated melt recharged process was demonstrated on bench tests but was not installed in the growth system. An RF heating/cooling coil for accelerated throughput was shown not to be feasible. An inverted cone heat shield was developed which accelerates charge melt-in and permits faster crystal growth. A micro-processor based process was tested. Results of the tests indicated an improved micro-processor system would be necessary for commercial operation.

Final report has been approved, printed, and distributed. The contract is being closed out.

Title: Phase 2 of the Array Automated Assembly Task
Contract Number: 955079
Directing Organization: Jet Propulsion Laboratory
Project Engineer: D. Burger
Telephone: (213) 577-9374
Contractor: Kinetic Coatings, Inc.
P.O. Box 416
South Bedford St.
Burlington, MA 01803
Principal Investigator:
Telephone:
Contract Period of Performance: **From:** 6/78 **To:** 1/81
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY78 $97,020 FY $ FY $ FY $
Cumulative Funding To Date: $97,020

Contract objective is to investigate the use of ion implantation, ion beam sputtering, and electron beam deposition techniques for a simplified process which may be applied to the automated manufacture of solar cells of optimum efficiency that are hermetically sealed against typical terrestrial environment. Optimum parameters, manufacturing process procedures, and sequences shall be prepared describing the techniques employed.

Contract is completed. All tasks were successfully accomplished.

Title:	Automated Solar Module Assembly Line	**Contract Number:**	955287
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	D. Burger	**Telephone:**	(213) 577-9374
Contractor:	Kulicke and Soffa Industries, Inc. 507 Prudential Road Horsham, PA 19044		
Principal Investigator:	M. Bycer	**Telephone:**	(215) 674-2800
Contract Period of Performance:	**From:** 12/78 **To:** 10/80		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY79 $340,000 FY80 $145,789 FY $ FY $		
Cumulative Funding To Date:	$485,789		

Contract objectives are to design, build, debug, and deliver to JPL an automated assembly line for a typical solar module and solar cell to be approved by JPL.

Contract is completed. All tasks were successfully accomplished. Due to funding and programmatic considerations the assembly line was not delivered to JPL.

Title:	Process Feasibility Study in Support of Silicon Material Task I	**Contract Number:**	954343
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	R. Lutwack	**Telephone:**	(213) 354-7648
Contractor:	Lamar University P.O. Box 10053 Beaumont, TX 77710		
Principal Investigator:	C. Yaws	**Telephone:**	(713) 838-8310
Contract Period of Performance:	**From:** 10/75 **To:** 2/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task		
Contract Funding:	FY77 $99,962 FY78 $205,480 FY79 $262,098 FY80 $(37,540)		
Contract Funding:	FY81 $60,000		
Cumulative Funding To Date:	$590,000		

Contract objective is to perform investigations and analysis of processes for the low-cost, high-volume production of silicon suitable for solar cells by evaluating the commercial practicality of the processes.

This contract is completed and the final report written.

Chemical engineering analyses involving the preliminary process design of plants (1000-MT/yr capacity) to produce silicon via various technologies were accomplished for six processes: Union Carbide Corp. silane-to-silicon process; two versions of the Battelle Columbus Lab process based on zinc reduction of $SiCl_4$; the conventional poly-silicon process (Siemens technology); the SiI_4 decomposition process; and the Hemlock process based on deposition of Si from dichlorosilane. For all but the latter, economic analyses were accomplished for 1000-MT/yr plants. Major physical thermodynamic and transport property data were compiled, and some property data were experimentally determined.

This study is being continued under Contract No. 956045 to Texas Research and Engineering Institute, Inc.

Title:	Evaluation of Laser Annealing of Solar Cells — **Contract Number:** 955696
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	D. Burger — **Telephone:** (213) 577-9374
Contractor:	Lockheed Missiles and Space Co., Inc. 1111 Lockheed Way Sunnyvale, CA 94086
Principal Investigator:	J. Katzeff — **Telephone:** (408) 743-0466
Contract Period of Performance:	**From:** 3/80 **To:** 6/81
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding:	FY80 $100,000 FY81 $65,047 FY $ FY $
Cumulative Funding To Date:	$165,047

Contract objective is to evaluate laser annealing of silicon wafers in the manufacture of solar cells.

Contract is complete. All tasks were successfully accomplished with a laser anneal spot size of 30-mm diameter as a major achievement.

Title:	Development of Synthetic Procedures for Polymeric Ultraviolet Stabilizers and Absorbers — **Contract Number:** 955531
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	A. Gupta — **Telephone:** (213) 354-5783
Contractor:	University of Massachusetts Office of Grant and Contract Administration Graduate Research Center Amherst, MA 01003
Principal Investigator:	Otto Vogl — **Telephone:** (413) 545-0433
Contract Period of Performance:	**From:** 8/79 **To:** 12/81
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task
Contract Funding:	FY79 \$15,000 FY80 \$32,000 FY81 \$38,000 FY \$
Cumulative Funding To Date:	\$85,000

Contract objectives are to develop synthetic procedures for certain polymerizable ultraviolet stabilizers and absorbers and study their copolymerization with methyl and butyl esters of methacrylic acid; and to develop candidate film materials which may function as outer covers for solar modules and which meet cost and reliability goals.

The University of Massachusetts has successfully grafted 5-vinyl tinuvin to a wide variety of polymers including EVA, PMMA, polycarbonate, nylon and PnBa. Development of other (more available) UV stabilizers has resulted in the synthesis and copolymerization of 2(2-hydroxy-5-isopropenylphenyl) 2H-benzotriazole (2H5P). Based on the same intermediates as those used for the synthesis of 2H5P, a new synthesis of 2(2-hydroxy-5-vinylphenyl) 2H-benzotriazole (2H5V) has been carried out that promises to have advantages over 2H5P. Grafting of 2H5V onto a number of common polymers has been accomplished, including atactic polypropylene, polyethylene-co-vinyl acetate, PMMA, polybutyl acrylate and polycarbonate. Efforts are continuing to establish the most effective derivative of 2(2-hydroxyphenyl) 2H-benzotriazole as the prime candidate for polymerizable UV stabilizers for the FSA Project. Springborn, with JPL, has begun the evaluation of new polymeric and monomeric UV stabilizers and high-performance anti-oxidants available from American Cyanamid Co. for evaluation as long-life stabilization additives for low-cost encapsulation materials.

Title:	Investigation of the Hydrochlorination of Metallurgical-Grade Silicon	**Contract Number:**	955382
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	G. Hsu	**Telephone:**	(213) 354-7428
Contractor:	Massachusetts Institute of Technology Office of Sponsored Programs Cambridge, MA		
Principal Investigator:		**Telephone:**	(617) 253-1858
Contract Period of Performance:	**From:** 4/79 **To:** 7/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task		
Contract Funding:	FY79 $80,000 FY80 $120,000 FY81 $43,194 FY $		
Cumulative Funding To Date:	$243,194		

Contract objective is to provide data for the reaction for the hydrochlorination of metallurgical-grade silicon and silicon tetrachloride ($SiCl_4$) to form trichlorosilane ($SiHCl_3$) for producing low-cost high-purity silane. The goal of this contract is to support the Union Carbide Silane-to-Silicon Process conducting experimental and theoretical studies in the following areas: reaction kinetics and role of the catalyst in the hydrochlorination of metallurgical grade silicon; and optimization of operating conditions for the hydrochlorination step.

This contract was completed and the final report issued. Reaction kinetic experiments were carried out as functions of reaction pressure, reaction temperature, and hydrogen/$SiCl_4$ feed ratio. The effect of copper catalyst on the reaction rate was studied, as well as the effect of prolonged reaction. A corrosion study was made on type 304 stainless steel and on Inconel 800H under actual reactor conditions.

The process was found to be an efficient one for producing $SiHCl_3$ in good conversion rates and high yields. Copper is an effective catalyst.

This study is being continued under Contract No. 956061 to Solarelectronics, Inc.

Title:	Analysis of Defect Structure in Silicon
Contract Number:	955676
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	T. O'Donnell
Telephone:	(213) 354-5465
Contractor:	Materials Research, Inc. 790 E. 700 South Centerville, UT 84014
Principal Investigator:	Dr. R. Natesh
Telephone:	(801) 298-4000
Contract Period of Performance:	**From:** 6/80 **To:** 1/82
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task
Contract Funding:	FY80 $80,000 FY $ FY $ FY $
Cumulative Funding To Date:	$80,000

Contract objective is to perform quantitative defect analysis, using quantititative microscopy equipment, of selected silicon sheet samples. Defect analysis shall include characterization of grain size, dislocation density, twin boundary spacing, twin boundary density, and density of precipitates.

Procedures have been developed for accurate, reproducible, and quantitative analysis of silicon sheet defect structure. A Quantimet (QTM-720) Image Analyzing System, incorporating a PDP 11/03 minicomputer with dual floppy disc drive, high speed printer, Field Image Feature Interface (FIFI) Module, and an automated X-Y specimen stage control, has been and is being used in this development/evaluation program. A computer program for defect characterization of silicon was developed and submitted to JPL as a new technology item.

November 1981. The analyses of about one hundred and ninety (190) silicon sheet samples, approximately 800 cm^2, for twin boundary density, dislocation pit density, precipitate density, and grain boundary length has been accomplished. One hundred and fifteen (115) of these samples were manufactured by Crystal Systems, Inc. using their Heat Exchanger Method (HEM), thirty-eight (38) by Mobil-Tyco using Edge-defined Film-fed Growth (EFG), twenty (20) by Honeywell using the Silicon Ceramics (SOC) process, and ten (10) by Westinghouse using the Dendritic Web process. Seven (7) solar cells were also step-etched to determine the internal defect distribution on these samples.

Title:	Determine Effects of Pressure of Reactant Gases where Si is in Contact with Die and Container and Container Metals	**Contract Number:**	955415
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	M. Hagan	**Telephone:**	(213) 354-6998
Contractor:	University of Missouri 215 University Hall Columbia, MO 65211		
Principal Investigator:	D. Ownby	**Telephone:**	(314) 341-4406
Contract Period of Performance:	**From:** 5/79 **To:** 3/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY79 $20,000 FY80 $39,799 FY81 $28,000 FY $		
Cumulative Funding To Date:	$87,799		

Contract objectives include determination of effect of varying partial pressures of reactant gases, primarily oxygen, in a furnace atmosphere where molten silicon is in contact with die and container refractory materials; and determination of the extent of reaction between molten silicon and refractory materials at the interfacial reaction zones as a function of the partial pressure of the reactant gases.

UMR visited Westinghouse and measured the partial pressure of oxygen in their silicon web furnace. The PO_2 in their argon purge lines was determined to be $10^{-12.5}$ atmosphere at 1000°C, and approximately the same during growth at 1420°C.

Similar measurements were made at Honeywell in the silicon-on-ceramic facility. The PO_2 in their skim coater at 1420°C was 10^{-16} atmosphere with no parts open; and increased to $10^{-13.2}$ atmosphere during boron doping and melt replenishment. The PO_2 varied between these levels as the ceramic substrate was being coated.

For comparison purposes, the PO_2 in the Mobil-Tyco EFG silicon ribbon furnace was found to be $10^{-12.1}$ atmosphere.

All technical experiments on this contract have ceased; however, the final report has not yet been received.

Title: Design of Block V Solar Cell Modules 1981
Contract Number: 956099
Directing Organization: Jet Propulsion Laboratory
Project Engineer: R. Greenwood
Telephone: (213) 577-9290
Contractor: Mobil-Tyco Solar Energy Corporation
16 Hickory Drive
Waltham, MA 02154
Principal Investigator: E. Tornstrom
Telephone: (617) 890-0909
Contract Period of Performance: **From:** 8/81 **To:** 12/81
Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area
Contract Funding: FY $44,000 FY $ FY $ FY $
Cumulative Funding To Date: $44,000

Contract objective is to design residential load solar cell modules designed to incorporate such new features from the Project work or other sources that lead to lower unit module cost, higher module efficiency, or improvement of other factors commensurate with meeting the Project price and production goals. (Block V Solar Cell Module Design and Test Specifications for Residential Applications - 1981 - Document 5101-162.)

Module design is nearly complete. Engineering and Manufacturing Documentation as well as the Inspection System Plan are being prepared for the Preliminary Design Review scheduled for January 7, 1982.

Title: Edge-Defined Film-Fed Growth for Silicon Growth Development
Contract Number: 954355
Directing Organization: Jet Propulsion Laboratory
Project Engineer: R. Kachare
Telephone: (213) 354-4583
Contractor: Mobil-Tyco Solar Energy Corporation
16 Hickory Drive
Waltham, MA 02156
Principal Investigator: F. Wald
Telephone: (617) 890-0909
Contract Period of Performance: **From:** 10/75 **To:** 12/81
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task
Contract Funding: FY75 $259,353 FY76 $795,000 FY77 $1,010,423 FY78 $777,010
Contract Funding: FY79 $965,996 FY80 $659,042
Cumulative Funding To Date: $4,466,826

Contract objective is to develop methods of producing large areas of silicon ribbon by the edge-defined film-fed growth (EFG) technique directed toward minimum cost processing of silicon ribbons of a quality suitable for producing solar cells with a terrestrial efficiency greater than 10% and having a potential to be scaled for large quantity production.

The simultaneous melt replenishment for EFG multiple ribbons (3 ribbons, each 10-cm wide and ~0.025-cm thick) has been demonstrated for a one day growth cycle. A new prototype machine (machine 21) to grow multiple EFG ribbons (4 ribbons, each 10-cm wide) has been designed and fabricated. Theoretical and experimental thermal stress analysis on the EFG ribbon is being continued.

Title: Anti-Reflective Coatings on Large Area Glass Sheets
Contract Number: 955339
Directing Organization: Jet Propulsion Laboratory
Project Engineer: F. Bouquet
Telephone: (213) 354-4482
Contractor: Motorola, Inc.
Semiconductor Group
5005 E. McDowell Rd.
Phoenix, AZ 85008
Principal Investigator: E. Pastirik
Telephone: (602) 244-5511
Contract Period of Performance: **From:** 1/79 **To:** 10/80
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task
Contract Funding: FY79 $170,622 FY $ FY $ FY $
Cumulative Funding To Date: $170,622

Contract objective is to conduct detailed studies and testing of anti-reflective (AR) coatings for soda-lime glass resulting in perfected low-cost processes for producing a long-life (20-year minimum) AR costing on large area sheets of glass (up to 48 x 48 in.). The methods of production shall consist of applying a uniform film of sodium silicate to the sunlit surface of the glass followed by treatment with sulfuric acid.

All work on this contract has been satisfactorily completed, final report was received and distributed in the first quarter of FY 1981 and the contract is now closed.

Title: The Development of a Method of Producing Etch Resistant Wax Patterns on Solar Cells.
Contract Number: 955324
Directing Organization: Jet Propulsion Laboratory
Project Engineer: D. Burger
Telephone: (213) 577-9374
Contractor: Motorola, Inc.
Semiconductor Group
5005 E. McDowell Rd.
Phoenix, AZ 85008
Principal Investigator:
Telephone:
Contract Period of Performance: **From:** 1/79 **To:** 1/81
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY79 $177,841 FY $ FY $ FY $
Cumulative Funding To Date: $177,841

Contract objective is to conduct detailed studies to develop a technique to print etchant resistant wax patterns on solar cells which shall include wax printing process and apparatus design development, material characterization, selection process confirmation, and economic analysis.

Contract is completed. Studies did not result in a usable, etchant resistant wax pattern process.

Title: Establishment of a Production-Ready Manufacturing Process Utilizing Thin Silicon Substrates for Solar Cells

Contract Number: 955328

Directing Organization: Jet Propulsion Laboratory

Project Engineer: P. Alexander

Telephone: (213) 577-9324

Contractor: Motorola, Inc.
Semiconduction Group
5005 East McDowell Rd.
Phoenix, AZ 85008

Principal Investigator: R. Pryor

Telephone: (602) 244-5511

Contract Period of Performance: **From:** 1/79 **To:** 1/80

Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area

Contract Funding: FY79 \$260,000 FY80 \$82,351 FY \$ FY \$

Cumulative Funding To Date: \$342,351

Contract objectives are to investigate, develop, and characterize methods to establish a production-ready manufacturing process which uses thin silicon substrates for solar cells.

The contract is completed. All objectives of the contract were met. The final report was approved and distributed in October 1980.

Title: Processing Experiments on Non-Czochralski Silicon Sheet

Contract Number: 955844

Directing Organization: Jet Propulsion Laboratory

Project Engineer: C. Radics

Telephone: (213) 577-9402

Contractor: Motorola, Inc.
Semiconductor Group
5005 E. McDowell Rd.
Phoenix, AZ 85008

Principal Investigator: R. Pryor

Telephone: (602) 244-5511

Contract Period of Performance: **From:** 10/80 **To:** 4/81

Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area

Contract Funding: FY81 \$294,000 FY \$ FY \$ FY \$

Cumulative Funding To Date: \$294,000

Contract objective is to develop a low-cost process sequence for the manufacture of solar cells from non-Czochralski silicon sheet forms using ribbon-to-ribbon substrates grown from chemical vapor deposition feedstock by laser zone regrowth.

Contract has been successfully completed. Draft final report has been submitted to JPL and has been accepted subject to minor addition. The publication of the Final Report is expected during the second quarter of FY 1982.

Progress was achieved in the following:

1. Application of low-cost processing to non-Czochralski sheet material.
2. Optimized metal contact pattern design method.
3. Alternate cost analysis technique developed and compared with SAMICS.

Title:	Design, Fabrication, Test, Qualification, and Price Analysis of "Third Generation" Design Solar Cell Modules	**Contract Number:**	955406
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	M. Smokler	**Telephone:**	(213) 577-9238
Contractor:	Motorola, Inc. Semiconductor Group 5005 E. McDowell Rd. Phoenix, AZ 85008		
Principal Investigator:	B. Larson	**Telephone:**	(602) 244-6496
Contract Period of Performance:	**From:** 5/79 **To:** 3/80		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY79 $107,500 FY $ FY $ FY $		
Cumulative Funding To Date:	$107,500		

Contract objectives are to design, fabricate, test, qualify, deliver pre-production solar cell modules which comply with requirements of JPL Document 5101-16 Rev. A, entitled, "Block IV Solar Cell Module Design and Test Specification for Intermediate Load Center Applications." Prepare also a standardized price estimate for 10, 100, and 1000 kW of modules delivered in 1980.

Minor re-design resulted in modules passing qualification tests. All documentation has been delivered. Contract is completed.

Title:	Development of Fluidized Bed Silicon Technology	**Contract Number:**	956133
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	G. Hsu	**Telephone:**	(213) 354-7428
Contractor:	Oregon State University Corvallis, OR 97331		
Principal Investigator:	Octave Levenspiel	**Telephone:**	
Contract Period of Performance:	**From:** 9/24/81 **To:** 9/30/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task		
Contract Funding:	FY81 $30,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$30,000		

Contract objective is to obtain experimental data to characterize the fluidized bed reactor technology for use in converting silane to silicon. The experimental data are intended to provide a basis for determining the applicability of this technology for this chemical conversion.

Contract effort has not started. It will likely be delayed.

Title:	Analyses and Evaluation of Module Experimental Process System Development Unit (MEPSDU) Processes	**Contract Number:**	956034
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	B. Gallagher	**Telephone:**	(213) 577-9225
Contractor:	The Trustees of the Univ. of Pennsylvania 3451 Walnut St., I6 Philadelphia, PA 19104		
Principal Investigator:	M. Wolf	**Telephone:**	(215) 243-4822
Contract Period of Performance:	**From:** 5/81 **To:** 5/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY81 $59,691 FY $ FY $ FY $		
Cumulative Funding To Date:	$59,691		

Contract objective is to perform expert analysis and critical evaluation of processes as proposed or designed by Module Experimental Process System Development Unit (MEPSDU) Contractors including MEPSDU support contractors. Objective also is to define critical areas requiring research to advance state-of-the-art efficiencies.

Performed critical evaluation of both MEPSDU proposed process sequences. Performed critical review and analysis of the data made available in the monthly technical progress reports. Initiated study to define critical areas requiring research to advance state-of-the-art efficiencies in silicon solar cells fabricated by both MEPSDU Contractors.

Title:	Analysis of Evaluation of Processes and Equipment	**Contract Number:**	954796
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	P. Stella	**Telephone:**	(213) 354-9225
Contractor:	The Trustees of the University of Pennsylvania 3451 Walnut Street, I6 Philadelphia, PA 19104		
Principal Investigator:	M. Wolfe	**Telephone:**	(215) 243-4822
Contract Period of Performance:	**From:** 7/77 **To:** 3/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY78 $214,285 FY79 $41,780 FY80 $150,821 FY $		
Cumulative Funding To Date:	$406,886		

Contract objective is to perform expert analysis and critical evaluation of processes and equipment, proposed or designed, for the high-volume production modules.

The contract has been completed. A final report, covering the program analyses and evaluation, was published and distributed during the third quarter of 1981. The major areas of surface preparation, junction formation, metallization, and assembly as assessed and developed by all contractors under the Cell and Module Formation Research Area were covered. In particular cost comparisons of the processes along with process sensitivities were analyzed in detail.

Title:	Development of Technique for AR Coating and Nickel and Copper Metallization of Solar Cells
Contract Number:	955986
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	C. Radics
Telephone:	(213) 577-9402
Contractor:	Photowatt International, Inc. 2414 West 14th St. Tempe, AZ 85281
Principal Investigator:	—
Telephone:	
Contract Period of Performance:	**From:** 5/81 **To:** 6/82
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding:	FY81 $79,000 FY $ FY $ FY $
Cumulative Funding To Date:	$79,000

Contract objective is to perform analysis and evaluation of the technical feasibility and cost effectiveness of a system for metallizing silicon solar cells.

Significant technical problems were encountered in metallization. Recent reports of successful nickel coating have not been verified. Due to changes in personnel the contract is significantly under spent. A three-month extension of the effort is expected.

Title:	Design of Block V Solar Cell Modules 1981
Contract Number:	956100
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	M. Smokler
Telephone:	(213) 577-9238
Contractor:	RCA Corporation Advanced Technology Laboratory Front and Cooper Streets Camden, NJ 08102
Principal Investigator:	M. Levene
Telephone:	(609) 339-3663
Contract Period of Performance:	**From:** 9/81 **To:** 1/81
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area
Contract Funding:	FY81 $76,000 FY $ FY $ FY $
Cumulative Funding To Date:	$76,000

Contract objective is to design intermediate-load solar cell modules incorporating such new features from the Project work or other sources that lead to lower unit module cost, higher module efficiency, or improvement of other factors commensurate with meeting the Project price and production goals. (Block V Solar Cell Module Design and Test Specifications for Residential Applications - 1981 - Document 5101-161.)

Design concept is defined. Drawings and inspection system plan are in preparation, but behind schedule, so the Design Review will be about three weeks late.

Title:	Evaluation and Verification of Epitaxial Process Sequence for Silicon Solar Cell Production	**Contract Number:**	955825
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	J. Behm	**Telephone:**	(213) 577-9563
Contractor:	RCA Corporation RCA Laboratories Princeton, NJ 08540		
Principal Investigator:	D. Redfield	**Telephone:**	(609) 734-2442
Contract Period of Performance:	**From:** 1/81 **To:** 4/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY81 $100,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$100,000		

Contract objective is to implement a process evaluation and verification program for the economical manufacture of flat-plate photovoltaic silicon solar cell modules. The goal of the program shall be a quantitative assessment of the performance of cells and mini-modules produced by a manufacturing process sequence that has the potential of reducing module cost.

The following was accomplished prior to contract termination which was caused due to a lack of funds:

1. A baseline cell sequence was selected ($POCl_3$ junction diffusion, thick film screen printed Ag front grid, thick film Al back contact, sprayed-on AR coating).
2. Two potentially lower cost substrate material sources were selected: (1) HEM Si from Crystal Systems, Inc.; and (2) UMG* from Hemlock Semiconductor Corp.
3. Epitaxial deposition baseline process was completed (20 μm thickness) using the RCA's new HTR** processing 59 large area substrates at a time.
4. A limited number of cells were fabricated using Hemlock material. Cell performance was poor due to high contract resistance problems. Contract termination prevented solving of this problem.
5. A preliminary SAMIS analysis suggested that the process had the potential for high rate module cost of $0.49/up.

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*UMG - Upgraded Metallurgical Grade Si

**HTR - High Throughput Reactor.

Title:	Development of Megasonic Cleaning for Silicon Wafers	**Contract Number:**	955342
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	D. Boyd	**Telephone:**	(213) 577-9236
Contractor:	RCA Corporation RCA Laboratories Princeton, NJ 08540		
Principal Investigator:	A. Mayer	**Telephone:**	
Contract Period of Performance:	**From:** 3/79 **To:** 2/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY79 $181,676 FY $ FY $ FY $		
Cumulative Funding To Date:	$181,676		

Contract objectives are to develop and demonstrate a continuous megasonic cleaning process for silicon wafers having a diameter of three inches or larger. A slight cell efficiency improvement was demonstrated but repeatability of process results is uncertain. The cleaning solution, as developed, is an improvement in terms of cost, safety, and ecology of waste disposal. The megasonic cleaning process is commercially available.

Title:	Study Program for Encapsulation Materials Interface for Low-Cost Silicon Solar Array	**Contract Number:**	954739
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	E. Cuddihy	**Telephone:**	(213) 354-3188
Contractor:	Rockwell International Corp. Science Center P.O. Box 1085 Thousand Oaks, CA 91360		
Principal Investigator:	D. H. Kaelble	**Telephone:**	(904) 498-4545
Contract Period of Performance:	**From:** 3/77 **To:** 2/83		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task		
Contract Funding:	FY77 $30,000 FY78 $103,700 FY79 $99,660 FY80 $92,400		
Contract Funding:	FY81 $115,755		
Cumulative Funding To Date:	$441,515		

Contract objectives are to study encapsulation materials interface problems, through a physical/chemical study of surface and interfacial degradation mechanism, induced by the singular and combined effects of moisture, temperature, and U.V. radiation; and to develop necessary theoretical and experimental methods for assuring the quality and life potential of adhesively bonded interfaces, and the requirements of encapsulation systems relative to corrosion protection. An experimental study aimed at developing and then validating one or more corrosive models is to be carried out.

Significant progress toward identification of criteria and design principles for achieving strong, stable bonding of polymers to metals, such as EVA to solar cell metallization, continues. Some emerging criteria are: the metal surfaces must be clean and readily wetted by the polymer (to eliminate a surface layer of air), and the metal must be activated before priming by exposure to alkaline solutions (i.e., NaOH). The primer, on the other hand, must have acidic character.

A requirement for metallic corrosion is the presence of liquid water on the metal surface. Preliminary indications suggest that if the criteria for achieving strong, stable bonding of polymers to metals is met, liquid water is precluded from being present on the metal surface. This work continues.

Title: A Study of Effect of Impurities in Silicon Material — **Contract Number:** 954685
Directing Organization: Jet Propulsion Laboratory
Project Engineer: A. Yamakawa — **Telephone:** (213) 577-9092
Contractor: C. T. Sah Associates
403 Pond Ridge Lane
Urbana, IL 61801
Principal Investigator: C. T. Sah — **Telephone:** (217) 328-1925
Contract Period of Performance: **From:** 2/9/77 **To:** 10/31/81
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task
Contract Funding: FY77 $36,158 FY78 $104,000 FY79 $59,000 FY80 $49,991
Contract Funding: FY81 49,503
Cumulative Funding To Date: $298,652

Contract objective is to conduct a program of study on the effects of impurities on the properties of silicon material and performance of silicon solar cells.

The effects of impurities on solar cell performance were investigated using the recombination centers introduced by zinc impurity. Computed values show that the impurity is more detrimental in p-base silicon than in n-base silicon.

The effects of cell thickness on the efficiency of back-surface-field solar cells with zinc impurity were also studied.

Title: Analysis of Cost-Effective Photovoltaic Panel Design Concepts Using Light Trapping — **Contract Number:** 955787
Directing Organization: Jet Propulsion Laboratory
Project Engineer: P. Alexander — **Telephone:** (213) 577-9324
Contractor: Science Applications, Inc.
1710 Goodridge Dr.
P.O. Box 1303
McLean, VA 22102
Principal Investigator: — **Telephone:** (202) 821-4499
Contract Period of Performance: **From:** 6/80 **To:** 5/81
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY80 $42,340 FY81 $2,997 FY $ FY $
Cumulative Funding To Date: $45,337

Contract objective is to conduct analysis and construct appropriate models for the relationship between both cell and module efficiencies and optical variables.

This contract is completed. All contract objectives were met. The final report was distributed in May 1981.

Title:	Design Fabrication, Test, Qualification and Price Analysis of "Third Generation" Design Solar Cell Modules	**Contract Number:**	955410
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	M. Smokler	**Telephone:**	(213) 577-9238
Contractor:	Sensor Technology, Inc. (Photowatt) 21012 Lassen St. Chatsworth, CA 91311		
Principal Investigator:	M. Keeling	**Telephone:**	(602) 894-9564
Contract Period of Performance:	**From:** 4/79 **To:** 4/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY79 $124,599 FY81 ($7,609) FY $ FY $		
Cumulative Funding To Date:	$116,990		

Contract objectives are to design, fabricate, test, qualify, and deliver pre-production solar cell modules.

The re-designed module did not pass the qualification tests because of some secondary mechanical and electrical problems. The design was corrected and all modules have been delivered. The modules have passed the thermal and humidity phases of qualification tests and are starting the mechanical phases. The SAMIS computer runs have been completed and the cost report is in preparation. All documentation should be delivered by mid-January 1982.

Title: Phase 2 of the Array Automated Assembly Task
Contract Number: 954865
Directing Organization: Jet Propulsion Laboratory
Project Engineer: E. Drouet
Telephone: (213) 577-9422
Contractor: Sensor Technology (Photowatt)
21012 Lassen Street
Chatsworth, CA 91311
Principal Investigator: G. Jones
Telephone: (602) 894-9564
Contract Period of Performance: **From:** 9/77 **To:** 6/80
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY77 $130,000 FY78 $264,890 FY79 $283,000 FY80 $42,000
Cumulative Funding To Date: $719,890

A process sequence shall be specified which, when automated, should have the potential of mass producing silicon solar cell array modules encapsulated for protection against the Earth environment. This sequence shall be critically analyzed for cost effectiveness, quantity throughput, and reproducibility of the product.

Photowatt developed an automatic spray-on machine for applying Polymer dopants, AR coatings, and BSF. This equipment was delivered to the laboratory.

Under this contract it was determined that a wetting agent must be applied to texturized wafers in order to obtain a uniform AR coating.

The microwave study revealed that existing equipment limitations must be overcome before this approach can be more fully investigated. The additional effort required was shown to be at the research level and therefore beyond the scope of this contract.

Contract was completed, with the final report accepted and distributed in December 1980.

Title: Development of Low-Cost Polysilicon Solar Cells
Contract Number: 955265
Directing Organization: Jet Propulsion Laboratory
Project Engineer: D. Burger
Telephone: (213) 577-9374
Contractor: Sensor Technology, Inc. (Photowatt)
21012 Lassen St.
Chatsworth, CA 91311
Principal Investigator: S. Rhee
Telephone: (602) 894-9564
Contract Period of Performance: **From:** 12/78 **To:** 4/81
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding: FY79 $162,236 FY $ FY $ FY $
Cumulative Funding To Date: $162,236

Contract objectives are to investigate, develop, and document improved methods for the production of low-cost, high energy-per-unit-area polysilicon solar cells greater than three inches diameter with a solar energy efficiency greater than or equal to 10%.

Contract is complete. Most tasks were successfully completed. Cell efficiencies up to 10.7% were achieved but lack of funding caused early end to optimization efforts.

Title:	Advanced I.D. Wafering Technology	**Contract Number:**	956043
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	K. Dumas	**Telephone:**	(213) 354-6546
Contractor:	Silicon Technology Corporation P.O. Box 310 48 Spruce Street Oakland, NJ 07436		
Principal Investigator:	Peter Aharonyan	**Telephone:**	(201) 337-3731
Contract Period of Performance:	**From:** 6/81 **To:** 6/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY81 $150,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$150,000		

Contract objective is to furnish labor, equipment, and materials necessary to develop and demonstrate an advanced Internal Diameter (ID) wafering technology capable of meeting specific Project goals for both single crystal and polycrystalline silicon ingots.

Fifteen-cm diameter ingots are routinely sliced at 2.5 in. per minute (goal is 4 in./min) and 10 cm x 10 cm cross-section ingots are sliced at 2 in./min. The number of wafers per cm for the 10 cm x 10 cm ingots has reached the goal of 25/cm, while the best achievement in this area for the 15 cm ϕ ingots is 16-17 wafers/cm (goal$\simeq$20/cm). With each type of ingot the yield remains greater than 90%. Major difficulties that remain with the technology are in decreasing the kerf loss and increasing the cutting speed.

Title:	Enhanced ID Slicing - Silicon Ingots	**Contract Number:**	955282
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	T. Daud	**Telephone:**	(213) 354-5782
Contractor:	Siltec Corporation 3717 Haven Avenue Menlo Park, CA 94025		
Principal Investigator:	G. Fiegl	**Telephone:**	(415) 365-8600
Contract Period of Performance:	**From:** 1/79 **To:** 5/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY79 $220,000 FY80 $129,466 FY $ FY $		
Cumulative Funding To Date:	$349,466		

Contract objectives are to develop and demonstrate enhanced Internal Diameter (ID) Slicing Technology for silicon ingots that will reduce the combined kerf and slice thickness in order to maximize slicing material utilization.

This effort, under the near-term implementation (Tsongas) was completed on October 31, 1980. The goals for this effort were to achieve 25 slices/cm (minimum thickness of wafer, 205μm) on 10 cm diameter silicon ingot at 1 wafer/min achieving a blade life of 4000 wafers.

The contractor's approach was:

a) to demonstrate ingot rotation, which was successfully done;

b) obtain low kerf I.D. blades, which was obtained by etching the blade core and diamond plating;

c) develop dynamic blade control with feedback loop which was not done successfully, yielding only 22 slices/cm at about 1/4 wafers per min., with a blade life of 200 to 300 wafers. This failure has been attributed to the limitation of the saw and to a greater extent a limitation of ingot rotation process itself.

A final report draft has been reviewed and approved after minor modification. The contract will be closed pending inventory transfer.

Title:	Development of Advanced Methods for Continuous Czochralski Growth	**Contract Number:**	954886
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	R. Kachare	**Telephone:**	(213) 354-4583
Contractor:	Siltec Corporation 3717 Haven Ave. Menlo Park, CA 94025		
Principal Investigator:	G. Fiegl	**Telephone:**	(415) 365-8600
Contract Period of Performance:	**From:** 9/77 **To:** 8/80		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY77 $180,000 FY78 $159,000 FY79 $225,580 FY80 $334,370		
Cumulative Funding To Date:	$898,950		

Contract objectives are to design and develop equipment and processes to demonstrate continuous growth of crystals by the Czochralski process suitable for processing into solar cells. Continuous is defined as the growth of at least 150 kg of silicon 150 mm in diameter from one growth container. The approach to meeting this goal is to develop a furnace with continuous liquid replenishment of the growth crucible.

The significant achievements for the Czochralski growth process for this contract are:

1. A furnace has been designed, fabricated, and evaluated for continuous liquid melt replenishment of the growth chamber.
2. Feasibility of liquid melt replenishment approach has been demonstrated.
3. A 65-kg silicon ingot was grown by using this approach—the largest silicon ingot grown to date by the Czochralski growth method.

The contract funding was terminated in August 1980. Grover (GFE) and remaining silicon and ingots will be delivered to JPL in the second quarter of FY 1982. The final report is due at that time also.

Title: Design, Fabrication, Test, Qualification and Price Analysis of "Third Generation" Design Solar Cell Modules
Contract Number: 955403
Directing Organization: Jet Propulsion Laboratory
Project Engineer: D. Runkle
Telephone: (213) 577-9214
Contractor: Solar Power Corporation
20 Cabot Rd.
Woburn, MA 01801
Principal Investigator: D. Dilts
Telephone: (617) 935-4600
Contract Period of Performance: **From:** 6/79 **To:** 1/81
Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area
Contract Funding: FY79 $129,863 FY $ FY $ FY $
Cumulative Funding To Date: $129,863

Contract objectives are to design, fabricate, test, qualify, and deliver pre-production solar cell modules which comply with requirements of JPL Document 5101-16 Rev. A, entitled, "Block IV Solar Cell Module Design and Test Specification for Intermediate Load Center Applications." Prepare also a standard price estimation for 10, 100, and 1000 kW of modules delivered in 1980.

This contract has been closed. The innovative designs developed under the contract proved to be unacceptable as commercial products and were abandoned by Solar Power. Modules were delivered, subjected to the tests, and proved unsatisfactory. Following the experience in this design contract, Solar Power did furnish JPL a set of JPL specifications 5101-16, Rev. A.

Title: Investigation of Hydrochlorination of $SiCl_4$
Contract Number: 956061
Directing Organization: Jet Propulsion Laboratory
Project Engineer: G. Hsu
Telephone: (213) 354-7428
Contractor: Solarelectronics, Inc.
Bellingham Industrial Park
P.O. Box 141, 21 Rita Lane
Bellingham, MA 02019
Principal Investigator: J. Mui
Telephone: (617) 966-1234
Contract Period of Performance: **From:** 7/81 **To:** 7/82
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task
Contract Funding: FY81 $35,000 FY $ FY $ FY $
Cumulative Funding To Date: $35,000

Contract objective is to obtain data to define process parameters, such as reaction kinetics, mass transfer requirements, fluidization mechanics, effects of impurities, corrosion measurements, materials of construction, and quality control for the hydrochlorination of silicon tetrachloride and metallurgical grade silicon metal to form trichlorosilane. The engineering data are intended to provide a base for optimizing the economics of the hydrochlorination process by reducing processing costs.

This is a new contract. To date, tasks completed are the Program Plan, the reactor design, and purchase of equipment. Tasks in progress are the construction and installation of the 2-in. diameter hydrochlorination reactor, preparation of test samples of various metal alloys for corrosion studies, safety review, start-up reactor, and carrying out hydrochlorination experiments.

Title:	Design of Block V Solar Cell Modules 1981	**Contract Number:**	956102
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	R. Greenwood	**Telephone:**	(213) 577-9290
Contractor:	Solarex Corporation 1335 Piccard Drive Rockville, MD 20850		
Principal Investigator:	J. Hoelscher	**Telephone:**	(301) 948-0202
Contract Period of Performance:	**From:** 8/81 **To:** 12/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY81 $44,500 FY $ FY $ FY $		
Cumulative Funding To Date:	$44,500		

Contract objective is to design intermediate load solar cell modules to incorporate such new features from the Project work or other sources that lead either to lower unit module cost, higher module efficiency, or improvement of other factors commensurate with meeting the Project price allocation and production goals. (Block V Solar Cell Module Design and Test Specification for Intermediate Load Applications - 1981 - JPL Document 5101-161.)

Module design is well underway. The Inspection System Plan and Engineering and Manufacturing Documentation are being prepared for the Preliminary Design Review scheduled for January 21, 1982.

Title:	Design, Fabrication, Test, Qualification and Price Analysis of "Third Generation" Design Solar Cell Modules	**Contract Number:**	955404
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	M. Smokler	**Telephone:**	(213) 577-9238
Contractor:	Solarex Corporation 1335 Piccard Drive Rockville, MD 20850		
Principal Investigator:	J. Wohlgemuth	**Telephone:**	(301) 948-0202
Contract Period of Performance:	**From:** 5/79 **To:** 2/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY79 $221,791 FY $ FY $ FY $		
Cumulative Funding To Date:	$221,791		

Contract objectives are to design, fabricate, test, qualify, and deliver intermediate load pre-production solar cell modules and residential load pre-production solar cell modules. Prepare a standardized price estimate with supporting analyses and input data for the approved module design for each of the two types of modules, using the Solar Array Manufacturing Industry Simulation (SAMIS) computer program.

The module design deficiencies have been corrected. All modules have been delivered. Both the intermediate load modules and the residential modules have passed the qualification tests. All documentation has been delivered. The contract is complete.

Title:	A Module Experimental Process System Development Unit (MEPSDU)	**Contract Number:**	955902
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	J. Behm	**Telephone:**	(213) 577-9563
Contractor:	Solarex Corporation 1335 Piccard Drive Rockville, MD 20850		
Principal Investigator:	J. Wohlgemuth	**Telephone:**	(301) 948-0202
Contract Period of Performance:	**From:** 11/80 **To:** 12/84		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY81 $689,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$689,000		

The contractor shall demonstrate the technical readiness of a cost-effective process sequence that has the potential for the production of flat-plate photovoltaic modules which meet a factory F.O.B. price goal in 1986 of 70¢ or less per peak watt (1980$). This goal assumes operation of the module in an insolation of 100 mW/cm^2, at a temperature of 28°C and in a spectrum represented by AM1. For this demonstration the Contractor shall (1) use material costs as projected in the SAMICS Cost Account Catalog and (2) assume operation of the modules under the conditions assumed in setting the goal.

The following progress has been made:

FY81

1. A baseline process sequence has been established.
2. A baseline module assembly design has been selected.
3. Large area solar cells (10 x 10 cm) have been fabricated in the laboratory using the complete baseline MEPSDU-S4 process sequence.
4. An automated cell/interconnect soldering machine Phase I contract has been completed by Kulicke & Soffa, Horsham, Penn., which established the detail features of the machine.

FY82

5. Starting in FY 1982, the program scope has been limited to cell fabriction only. All module assembly aspects are being eliminated and the residual program is being stretched out to accommodate reduced funding levels.

Title:	Phase 2 of the Array Automated Assembly Task	**Contract Number:**	954854
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	D. Burger	**Telephone:**	(213) 577-9374
Contractor:	Solarex Corporation 1334 Piccard Drive Rockville, MD 20850		
Principal Investigator:	J. Anderson	**Telephone:**	(301) 948-0202
Contract Period of Performance:	**From:** 9/77 **To:** 4/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY78 $392,171 FY79 $100,000 FY80 $104,056 FY81 $6,500		
Cumulative Funding To Date:	$602,727		

A process sequence shall be specified which, when automated, would have the potential of mass producing silicon solar cell array modules encapsulated for protection against the Earth environment. This sequence shall be critically analyzed for cost effectiveness, quantity throughput, and reproducibility of the product.

Phase I effort resulted in a low-cost process sequence with good potential for mass production. One area in this sequence was the electroless nickel plated/solder dipped metallization system. Phase 2 was initiated in 1980 to clarify the cost and reliability aspects of the metallization system. Five tasks were to be performed:

1. Effects of surface oxide thickness and sintering temperature;
2. Environmental testing of electroless nickel contacts;
3. Nickel penetration of silicon;
4. Effect of nickel plating solution on solar cells;
5. Evaluation of Motorola electroless plating process.

Contract was completed. All tasks were accomplished.

Title:	High Resolution, Low-Cost Solar Cell Contact Development	**Contract Number:**	955725
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	B. Gallagher	**Telephone:**	(213) 577-9225
Contractor:	Spectrolab, Inc. 12500 Gladstone Ave. Sylmar, CA 91342		
Principal Investigator:	N. Mardesich	**Telephone:**	(213) 365-4611
Contract Period of Performance:	**From:** 6/80 **To:** 8/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY81 $149,799 FY $ FY $ FY $		
Cumulative Funding To Date:	$149,799		

Contract objective is to demonstrate the technical and economic feasibility of the "MID-FILM" process for depositing solar cell collector grid metallization with a potential, when automated, of mass producing silicon solar cells at low-cost for use in solar cell array modules in terrestrial environments.

Contract has been completed. All deliverables have been received. A viable process has been developed using both a Ag contact system and a more cost effective MoSn contact system.

Title:	The Design, Analysis, and Test Verification of Advanced Encapsulation Systems	**Contract Number:**	955567
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	E. Cuddihy	**Telephone:**	(213) 354-3188
Contractor:	Spectrolab, Inc. 12500 Gladstone Ave. Sylmar, CA 91342		
Principal Investigator:	A. Garcia	**Telephone:**	(213) 365-4611
Contract Period of Performance:	**From:** 11/79 **To:** 12/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task		
Contract Funding:	FY81 $300,000 FY82 $358,000 FY $ FY $		
Cumulative Funding To Date:	$658,000		

Contract objective is to prepare a prototype encapsulation system design with recommended material selections and fabrication processes, including a detailed design analysis of the predicted optical, electrical, thermal, and structural performance of the recommended design.

During the initial year of this contract, Spectrolab developed optical, thermal, electrical, and structural analytical computer models for the analysis and performance assessment of module encapsulation systems. Parametric and sensitivity studies provided design and performance optimization criteria relative to encapsulant material selection and material dimensions.

During the second year, material and module tests were conducted to verify the analysis tools developed during Phase I. This verification activity is still ongoing.

A major success has been the ability to represent the complicated structural design behavior of encapsulation systems in the form of reduced-variable master curves.

Title:	Development and Fabrication of a Solar Cell Junction Processing System	**Contract Number:**	955640
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	D. Fitzgerald	**Telephone:**	(213) 354-4792
Contractor:	Spire Corporation Patriots Park Bedford, MA 01730		
Principal Investigator:	A. Armini	**Telephone:**	(617) 275-6068
Contract Period of Performance:	**From:** 1/80 **To:** 2/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area		
Contract Funding:	FY80 $865,000 FY81 $600,000 FY $ FY $		
Cumulative Funding To Date:	$1,465,000		

Contract objectives are to develop, construct, and deliver a junction processing system which shall be capable of producing solar cell junctions by means of ion implantation followed by pulsed electron beam annealing. The machine shall be capable of processing 4-in. diameter single crystal Czochralski wafers at a rate of 10 million wafers per year.

The pulsed electron beam annealer (PEBA) was designed, fabricated, and tested during FY 1981. The PEBA is capable of annealing damage due to ion implantation and electrically activating the dopant on 4-in. diameter silicon wafers at a rate of 10 million wafers/year. The PEBA resembles a well-controlled uniformly distributed lightning bolt which can melt a thin layer of the silicon surface in about 1/10 of a microsecond. The melted region regrows as single crystal from the undamaged substrate in a few microseconds.

A transport system was also designed, fabricated, and tested during this period. The transport system is capable of moving wafers at a throughput of 10 million wafers/year in and out of a vacuum environment, where the wafers are ion implanted and pulsed annealed. The transport consists of two loading and two unloading vacuum interlocks which can handle 50 wafer cassettes. The vacuum interlocks are alternated to maintain a continuous flow of wafers through the system. The wafers are moved in the vacuum chamber by means of a walking beam conveyer which delivers the wafers to the respective process stations; i.e., ion implant or PEBA.

Title:	Verification and Implementation of Electrostatic Bonding Technologies **Contract Number:** 955861
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	C. Coulbert **Telephone:** (213) 354-2610
Contractor:	Spire Corporation Patriots Park Bedford, MA 01730
Principal Investigator:	Peter Younger **Telephone:** (617) 275-6000
Contract Period of Performance:	**From:** 1/81 **To:** 4/81
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task
Contract Funding:	FY81 $49,000 FY $ FY $ FY $
Cumulative Funding To Date:	$49,000

The Contractor shall conduct a comprehensive program of investigation, verification, and implementation of previously developed or demonstrated Electrostatic Bonding (ESB) technologies. The program emphasis shall be focused upon the development of a process that is compatible with the use of low-cost performed contact fabrication and upon the design of a large area electrostatic bonder.

The contract was terminated on April 6, 1981.

A laboratory ESB bonder with microprocessor computers capable of producing 6-in. x 8-in. ESB Modules was fabricated. A pre-formed mesh metallization system was conceived and demonstrated. Several alternate designs and total encapsulation configurations were evaluated and test hardware produced for long-term durability testing. Several technical problems needing resolution in the scale-up development were identified and potential solutions proposed.

Title: Develop and Test Encapsulation Materials
Contract Number: 954521
Directing Organization: Jet Propulsion Laboratory
Project Engineer: Cliff Coulbert
Telephone: (213) 354-2610
Contractor: Spire Corporation
Patriots Park
Bedford, MA 01730
Principal Investigator: Peter Younger
Telephone: (617) 275-6000
Contract Period of Performance: **From:** 5/76 **To:** 10/80
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task
Contract Funding: FY76 $110,000 FY77 $324,648 FY78 $290,000 FY79 $250,067
Contract Funding: FY80 $154,032
Cumulative Funding To Date: $1,132,797

Contract objective is to conduct detailed studies, analyses, development, and testing of encapsulation systems to protect photovoltaic devices in the terrestrial environment which incorporate integrally bonded glass covers. Demonstrate potential for low cost, automated encapsulation of the solar cell modules to assure long service life with a goal of greater than 20 years.

As part of the contract, equipment and process parameters were developed for the use of electrostatic bonding of solar cells and metallization to glass to provide an integral encapsulation module configuration of great durability and service life. Test modules were provided for evaluation, optimum processing and module design parameters were identified, and design criteria was developed for scale-up of the process to full-size production modules.

A laboratory ESB bonder with microprocessor controls capable of producing 6-in. x 8-in. ESB modules routinely was fabricated. A preformed metal mesh metallization systems was conceived and demonstrated. Several alternate cell designs and total encapsulation configurations were evaluated and test hardware produced for long term durability testing. Several technical problems needing resolution in the scale-up development were identified and potential solutions proposed.

Title:	Design of Block V Solar Cell Modules 1981	**Contract Number:**	956103
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	R. Greenwood	**Telephone:**	(213) 577-9290
Contractor:	Spire Corporation Patriots Park P.O. Box 1 Bedford, MA 01730		
Principal Investigator:	P. Younger	**Telephone:**	(617) 275-6000
Contract Period of Performance:	**From:** 8/81 **To:** 12/81		
Project/Area/Task:	Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area		
Contract Funding:	FY81 $52,000 FY $ FY $ FY $		
Cumulative Funding To Date:	$52,000		

Contract objective is to design residential load solar cell modules designed to incorporate such new features from the Project work or other sources that lead to lower unit module cost, higher module efficiency, or improvement of other factors commensurate with meeting the Project price and production goals. (Block V Solar Cell Module Design and Test Specifications for Intermediate Load Applications - 1981 - JPL Document 5101-161.)

All contractually required supplies and services have been provided on schedule. These include (1) a Preliminary Design Review, (2) Documentation including (a) Monthly Letter Technical Report, (b) Design Review Data Package, (c) Preliminary Engineering and Manufacturing Documentation and (d) Preliminary Inspection System Plan and (3) attendance at FSA PIMs. The module design presented was responsive to the requirement of the Block V specification which demands more severe environmental testing, attention to safety, and fault tolerance that have not been required by previous specifications issued by JPL.

Title:	Module Encapsulation Task
Contract Number:	954527
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	E. Cuddihy
Telephone:	(213) 354-3188
Contractor:	Springborn Laboratories, Inc. Water Street - Hazardville Enfield, CT 06082
Principal Investigator:	P. Willis
Telephone:	(203) 749-8371
Contract Period of Performance:	**From:** 5/76 **To:** 8/82
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Array Area; Environmental Isolation Task
Contract Funding:	FY76 \$175,000 FY77 \$110,480 FY78 \$190,000 FY79 \$100,000
Contract Funding:	FY80 \$121,666 FY81 \$160,000
Cumulative Funding To Date:	\$857,146

Contract objectives are to conduct detailed studies, analyses, and testing of materials in order to identify and recommend material or materials and related processes suitable for low cost, automated encapsulation of solar cell modules, said encapsulation to protect the solar cells from terrestrial environment. Conduct an experimental program of development and characterization of specific encapsulation materials, specific encapsulation system, and associated processes and provide documentation.

Candidate materials and module fabrication processes have been identified for each of the module encapsulation functional elements including covers, pottants, structural panels, back covers, and edge seals. The list of candidates has been narrowed to the two or three most promising for each function. These candidates are undergoing intensive characterization and field testing relative to weatherability, photothermal stability, and processibility.

For pottants, the two most promising lamination film materials are ethylene vinyl acetate (EVA) and ethylene methyl acrylate (EMA), while the two most promising liquid casting materials are poly-n-butyl acrylate (P-N-BA) and aliphatic polyether urethane (PU). During FY 1981, EVA became a commercially available film product.

EMA and p-N-BA have recently become available in experimental quantities for application evaluation, and PU should also be available shortly.

Other encapsulation materials include low-iron tempered glass, Tedlar, acrylic films, mild steel and wood hardboard.

Future work includes development of module surfacing treatments for soil resistance, material additivies for improved photothermal stability of pottants and cover films, and design optimization for edge seals and gaskets.

Title:	Silicon Production Process Evaluation — **Contract Number:** 956045
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	R. Lutwack — **Telephone:** (213) 354-7648
Contractor:	Texas Research and Engineering Institute, Inc. 6116 Washington Groves, TX 77619
Principal Investigator:	Dr. Carl Yaws — **Telephone:** (713) 727-7439
Contract Period of Performance:	**From:** 5/18/81 **To:** 5/20/82
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task
Contract Funding:	FY81 $40,000 FY $ FY $ FY $
Cumulative Funding To Date:	$40,000

Contract objective is to perform production process evaluations. This analytical effort is to provide assessment of polysilicon production process developments, securing a basis for programmatic decisions of the Silicon Material Task. The contractor shall perform chemical engineering studies and analysis of the preliminary process design activities for the processes under consideration for production of silicon and perform economic and cost analyses of the polysilicon production processes being evaluated by the Silicon Material Task.

This contract, which is a follow-on to an earlier contract to Lamar University, was initiated in May 1981. Work to-date has consisted of chemical engineering analysis of the process being developed by Hemlock Semiconductor Corp. for producing silicon by chemical vapor deposition from dichlorosilane. This analysis is scheduled to be completed in January 1982.

Title:	Modeling of Photodegradation in Solar Cell Modules of Substrate and Superstrate Design Made with Ethylene Vinyl Acetate Poltant Material	**Contract Number:**	955591
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Gupta	**Telephone:**	(213) 354-5783
Contractor:	The Governing Council of the Univ. of Toronto Office of Research Administration - Simcoe Hall Toronto, Ontario, M5S 1A1, CANADA		
Principal Investigator:		**Telephone:**	
Contract Period of Performance:	**From:** 1/80 **To:** 4/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Environmental Isolation Task		
Contract Funding:	FY80 $55,000 FY81 $52,085 FY $ FY $		
Cumulative Funding To Date:	$107,085		

Contract objectives are to develop an analytical model of photodegradation of ethylene vinyl acetate (EVA) using real time test data on EVA encapsulated solar cell modules and laboratory data on EVA films free standing, under glass, or under other transparent covers/barriers; and to undertake verification and validation of analytical model of photodegradation of EVA heretofore developed.

A computer simulation program has been developed to predict long-term chemical changes based on generalized photo-oxidation mechanisms. An experimental validation program conducted with simple liquid alkanes using sensitive analytical probes to obtain required photo-oxidation data after short-term outdoor exposure is continuing.

The elementary reaction matrix for the computer simulation of photo-oxidation program has been revised resulting in a new scheme of 31 reactions. Control of integration parameters allowing more program flexibility has also been accomplished. The result is that without any arbitrary adjustment to the reaction rates, the computer simulation now shows EVA lifetimes in excess of ten years without UV screening when initiated by very small amounts of ketone, peroxide, or some fortuitous alkyl radical generating step.

Title: Automatic Equipment Development and Modification
Contract Number: 955699
Directing Organization: Jet Propulsion Laboratory
Project Engineer: P. Alexander
Telephone: (213) 577-9324
Contractor: Tracor MBAssociates
Bollinger Canyon Rd.
San Ramon, CA 94583
Principal Investigator: John Haggerty
Telephone: (415) 837-7201
Contract Period of Performance: **From:** 7/80 **To:** 10/81
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module-Formation Research Area
Contract Funding: FY80 $100,000 FY81 $153,936 FY $ FY $
Cumulative Funding To Date: $253,936

Contract objectives are to develop, test, and deliver automation equipment which, when used with a JPL-supplied Unimation Robot, shall be capable of interconnecting and emplacing solar cells in modular configuration, and to encapsulate and assemble solar cells.

The contract is completed and all contract objectives were met. The draft final report was approved in November 1981. Distribution of the final report and delivery of the automated equipment to JPL is scheduled for January 1982.

Title: Investigation of Solar Array/ Module Safety Requirements
Contract Number: 955392
Directing Organization: Jet Propulsion Laboratory
Project Engineer: R. Sugimura
Telephone: (213) 577-9118
Contractor: Underwriters Laboratories, Inc.
1285 Walt Whitman Rd.
Melville, NY 11746
Principal Investigator: A. Levins
Telephone: (516) 271-6200
Contract Period of Performance: **From:** 5/79 **To:** 11/81
Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area
Contract Funding: FY79 $65,730 FY80 $54,100 FY81 $111,689 FY $
Cumulative Funding To Date: $231,519

Contract objectives include to research array subsystem safety schemes; to characterize arcing phenomena related to ignition of materials; and to continue with research pertinent to module and panel safety requirements.

A draft final documenting the results of the work is currently being reviewed by JPL.

Title:	Silane to Silicon Process
Contract Number:	954334
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	G. Hsu
Telephone:	(213) 354-7428
Contractor:	Union Carbide Corp. Linde Division P.O. Box 44 Tonawanda, NY 14150
Principal Investigator:	H. Morihara
Telephone:	(716) 879-2582
Contract Period of Performance:	**From:** 10/75 **To:** 12/83
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task
Contract Funding:	FY76 $205,000 FY77 $1,328,379 FY78 $851,621 FY79 $1,236,000
Contract Funding:	FY80 $4,354,000 FY81 $5,402,000
Cumulative Funding To Date:	$13,377,000

Contract objective is to conduct a program to establish the practicality of a process for high-volume, low-cost production of silane (Step I); and the practicality of the subsequent pyrolysis of silane to semiconductor-grade silicon (Step II). The goal of Step I is to achieve a production cost of four dollars ($4) per kg of silane, and the goal of Step II is to pyrolyze the silane to semiconductor-grade silicon so as to meet the goals of the Silicon Material Task of $14 per kg of silicon in 1980 dollars.

This contract has demonstrated the technical feasibility of the silane-to-silicon process in laboratory process development units (Phase I) and has delivered a comprehensive process design (Phase II) package of a 100 metric ton/year Experimental Process System Development Unit (EPSDU). The silicon product price is estimated to be less than $14 per kg in 1980 dollars.

In Phase III EPSDU stage (from June 1979 to October 1981), the site preparation and civil construction of EPSDU was completed at E. Chicago, Indiana. Equipment was delivered to the site to be installed. However, as a result of several funding recisions and DOE/JPL program changes, all activities for constructing the EPSDU have been stopped. The only activity that JPL/DOE is funding is the fluidized bed silicon deposition R&D. DOE is currently considering the transfer of hardware to Union Carbide Corporation, who will complete the silane pilot plant as planned at UCC's own expense, and share the experimental data with DOE through JPL's continuous monitoring assistance in return for the property transfer. The evaluation and negotiation processes are underway.

Title: Silicon Dendritic Web Material Process Development	**Contract Number:** 955624
Directing Organization: Jet Propulsion Laboratory	
Project Engineer: B. Gallagher	**Telephone:** (213) 577-9225
Contractor: Westinghouse Electric Corporation 1310 Beulah Rd. Pittsburgh, PA 15235	
Principal Investigator: D. Meier	**Telephone:** (412) 892-5600
Contract Period of Performance: **From:** 3/80 **To:** 8/81	
Project/Area/Task: Flat-Plate Solar Array Project; Cell and Module Formation Research Area	
Contract Funding: FY80 $195,365 FY81 $93,953 FY $ FY $	
Cumulative Funding To Date: $289,318	

Contract objectives include to conduct a dendritic web development program to produce and deliver six meters of dendritic web per month (a total of thirty-six meters); determine conditions required to achieve a high yield of ultrasonic bonds on thick dendritic web; demonstrate the applicability of ultrasonic seam welding to the web; perform mechancial reliability tests on solar cell modules; determine the suitability of ethylene vinyl acetate and polyvinyl butyral as encapsulants for dendritic web material; produce and deliver four modules 30 cm x 60 cm in size using best technique available at end of first two months of the program; perform a cost analysis of a conceptual factory using dendritic web as the input sheet material; update SAMICS Format A data as processes are analyzed and completed.

Contract has been completed. The 36 m of web has been delivered, and 3 instead of 4 modules were delivered. The last module delivered was scaled up from 30 cm x 60 cm to 40 cm x 120 cm to show improvement in processing capability.

Title:	Module Experimental Process System Development Unit (MEPSDU) — **Contract Number:** 955909
Directing Organization:	Jet Propulsion Laboratory
Project Engineer:	P. Alexander — **Telephone:** (213) 577-9324
Contractor:	Westinghouse Electric Corp. Advanced Energy Systems Division P.O. Box 10864 Pittsburgh, PA 15236
Principal Investigator:	R. Campbell — **Telephone:** (412) 256-5485
Contract Period of Performance:	**From:** 11/80 **To:** 10/84
Project/Area/Task:	Flat-Plate Solar Array Project; Cell and Module Formation Research Area
Contract Funding:	FY81 $830,000 FY $ FY $ FY $
Cumulative Funding To Date:	$830,000

The contractor shall demonstrate the technical readiness of a cost-effective process sequence that has the potential for the production of flat-plate photovoltaic modules which meet a factory F.O.B. price goal in 1986 of 70¢ or less per peak watt (1980$). This goal assumes operation of the module in an insolation of 100 mW/cm^2, at a temperature of 28°C and in a spectrum represented by Air Mass-1 (AM1). For this demonstration the contractor shall (1) use material costs as projected in the SAMICS Cost Account Catalog and (2) assume operation of the modules under the conditions assumed in setting the goal.

A twenty-eight month subcontract with Kulicke and Soffa for an automated tabbing and stringing machine was let in December 1980, and is on schedule. Two design reviews have been completed—one in March 1981, a second in July 1981. The module design is now finalized. A base-line process sequence is now established. Engineering specifications have been completed on two pieces of processing equipment, a laser scribing machine and a cell and module test unit. Both items are now on order. Preliminary SAMICS costing analyses were completed and show a module cost of $0.709/W.

A spending rate reduction was imposed in May 1981, and a revised program plan was generated which indicated a 10-month slippage in contract completion date—from March 1983, to December 1983. A second spending rate reduction was imposed in September 1981, and a second revised program plan is now being generated which is anticipated to slip the completion date further.

Title: Part 2 - Develop and Define Requirements of Purity for Solar Cell Grade Silicon
Contract Number: 954331
Directing Organization: Jet Propulsion Laboratory
Project Engineer: A. Yamakawa
Telephone: (213) 577-9092
Contractor: Westinghouse Electric Corp.
1310 Beulah Rd.
Pittsburgh, PA 15235
Principal Investigator: R. S. Hopkins
Telephone: (412) 256-3235
Contract Period of Performance: **From:** 10/1/75 **To:** 11/81
Project/Area/Task: Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Silicon Material Task
Contract Funding: FY76 $341,521 FY77 $544,950 FY78 $467,000 FY79 $446,000
Contract Funding: FY80 $369,701 FY81 $251,423
Cumulative Funding To Date: $2,420,595

Contract objective is to study the effects of impurities and impurity concentrations on the performance of silicon solar cells. The object of the program is to develop and define requirements of purity for solar cell grade silicon.

Phases I, II, & III of this effort have been completed and final reports issued.

In Phase I, a set of empirical expressions was developed to relate the solar cell parameters of open circuit voltage, short circuit current, and efficiency to impurity content of the cell. A model in which impurities primarily degrade lifetime and reduce the short circuit current was shown to be consistent with lifetime and solar cell measurements.

In Phase II, the effects of thermal treatments, crystal growth rate, base doping concentration and type, grain boundary structure, and carbon/oxygen metal interactions were studied within the overall program to determine the effects of impurities on solar cell performance. That the impurity induced cell performance loss is primarily due to reduction in base diffusion length was firmly established. An analytical model based on this conclusion was developed to predict cell performance as a function of metal impurity content. The preliminary studies with polycrystalline cell performance were shown to be impurity species sensitive, and large fractions of the impurities were found to be segregated at the grain boundaries. The impurity concentration limits for polysilicon to be used for crystal growth methods, which have near-equilibrium segregation effects, were estimated for elements such as T_i (about 1 ppm) and Ni (about 100 ppm). The acceptable impurity limits depend on the assigned cell efficiency, crystal growth method, metal replenishment strategy, and cell process sequence.

In Phase III, the studies on the effects of thermochemical gettering treatments, base dopant concentration and type, and grain boundary-impurity interactions were continued along with investigations of the effects of nonuniformity of impurity distribution, long-term presence of impurities, and synergistic-complexing phenomena. Gettering action was shown to be directly dependent on magnitudes of the diffusion coefficients of the impurities. No evidence was found indicating large effects of nonuniform impurity distribution on cell performance, the variations being ±10%. From data for accelerated aging at high temperatures, it was shown that additional cell performance decreases are functions of diffusion rates; with M_o and T_i the projected stabilities were beyond 20 years. Detailed analyses of some polycrystalline cells showed that the relations of the impurity concentration and lifetime within grains were similar to that expected for single crystals and that the impurity concentrations near grain boundaries were less than within a grain. (Continued)

Title: Part 2 Develop and Define Requirements of Purity for Solar Cell Grade Silicon (Concluded) **Contract Number:** 954331
Directing Organization: Jet Propulsion Laboratory
Project Engineer: **Telephone:**
Contractor: Westinghouse Electric Corp.
Principal Investigator: **Telephone:**
Contract Period of Performance: **From:** **To:**
Project/Area/Task:
Contract Funding: FY $ FY $ FY $ FY $
Cumulative Funding To Date: $

Effort was begun on Phase IV in FY 1980 which included the study of impurity effects in polycrystalline silicon, identification of impurity thresholds for high-efficiency cells, assessment of process effects on impurity-doped cells, and identification of long-term impurity effects. It was found that the threshold for ingot structural breakdown is lower for polycrystalline growth than when growing single crystals, at least for the impurities iron, titanium, vanadium, chromium, and molybdenum.

This effort was continued through FY 1981 and final report is pending.

Title:	Web Dendritic Process Development	**Contract Number:**	954654
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Morrison	**Telephone:**	(213) 354-7200
Contractor:	Westinghouse Electric Corp. 1310 Beulah Road Pittsburgh, PA 15235		
Principal Investigator:	C. Duncan	**Telephone:**	(412) 256-3666
Contract Period of Performance:	**From:** 4/77 **To:** 11/80		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY77 $430,000 FY78 $692,869 FY79 $791,715 FY80 $731,508		
Cumulative Funding To Date:	$2,646,092		

Contract objective is to develop methods of production of large areas of silicon sheet by the web dendrite process directed toward minimum cost processing of silicon into sheets of a quality suitable for producing solar cells with a terrestrial efficiency greater than 12% and having potential to be scaled for large-quantity production.

A liquid level sensing system and a melt replenishment system were designed, built, and tested on the Web crystal growth system. Optimization of these systems were also continuous growth runs up to 72 hours in length necessary to achieve these cost goals of this process. Average solar cell efficiency greater than 12% were achieved.

Contract was completed and the final report submitted.

Title:	Dendritic Web Process Development	**Contract Number:**	955843
Directing Organization:	Jet Propulsion Laboratory		
Project Engineer:	A. Morrison	**Telephone:**	(213) 354-7200
Contractor:	Westinghouse Electric Corp. 1310 Beulah Road Pittsburgh, PA 15235		
Principal Investigator:	S. Duncan	**Telephone:**	(412) 256-3666
Contract Period of Performance:	**From:** 10/80 **To:** 9/82		
Project/Area/Task:	Flat-Plate Solar Array Project; Flat-Plate Collector Research Area; Large Area Silicon Sheet Task		
Contract Funding:	FY81 $927,266 FY $ FY $ FY $		
Cumulative Funding To Date:	$927,266		

Contract objectives are to design and fabricate a prototype web growth machine to complete process testing to meet Project technology readiness goals. Development shall be directed toward a web growth process capable of producing silicon sheet suitable for use as low-cost solar cells with a terrestrial efficiency greater than 15% and having potential to be scaled for large quantity. The cost goal is less than $700 (1980$) per peak kilowatt by 1985.

The prototype Experimental Sheet Growth Unit (ESGU) is fabricated and in daily operation. Experiments continue to increase throughput rates. Theoretical studies are being directly applied to growth system design to produce ribbon with less stress. Web dendrite solar cells $\geq 15\% \; \eta$ AM are being fabricated by Westinghouse in their R&D Center.

Massachusetts Institute of Technology
Lincoln Laboratory

Title: Programmable Load Assembly **Contract Number:** BX-694
Directing Organization: MIT Lincoln Laboratory
Project Engineer: B. E. Nichols **Telephone:** (617) 862-5500 ext. 234
Contractor: Control Technology Corporation
82 Turnpike Road
Westboro, MA 01581
Principal Investigator: **Telephone:**
Contract Period of Performance: **From:** 2/23/81 **To:** 4/1/81
Project/Area/Task: Southwest Residential Experiment Station
Contract Funding: FY81 $50,010 FY $ FY $ FY $
Cumulative Funding To Date: $50,010

Eight units were procured as part of the Residential Data System at the Southwest Residential Experiment Station.

Installation was completed in the third quarter of FY 1981. Residential Data System is operational.

Title: The Florida Solar Energy Center Experimental Photovoltaic Residential Facility - Operational Phase **Contract Number:** CX-3415
Directing Organization: MIT Lincoln Laboratory
Project Engineer: M. C. Russell **Telephone:** (617) 862-5500 x 5364
Contractor: Florida Solar Energy Center
P.O. Box 25000
Orlando, FL 32816
Principal Investigator: R. Okoniewski **Telephone:**
Contract Period of Performance: **From:** 7/1/81 **To:** 6/30/82
Project/Area/Task: Innovative Photovoltaic Applications for Residences
Contract Funding: FY81 $36,473 FY $ FY $ FY $
Cumulative Funding To Date: $36,473

This Innovative Photovoltaic Applications for Residences project on Cape Canaveral is supported in the areas of inverters, data acquisition equipment, and review of performance data.

The system and data acquisition equipment are operational; data acquisition will continue through June 30, 1982.

Title:	Maintenance Service on Solar Photovoltaic Power System at Natural Bridges National Monument, Utah	**Contract Number:**	BX-676 (previously BX-374)
Directing Organization:	MIT Lincoln Laboratory		
Project Engineer:	F. J. Solman	**Telephone:**	(617) 862-5500 x 7627
Contractor:	Ford, Bacon and Davis Utah Salt Lake City, UT		
Principal Investigator:	E. C. Rowan/L. P. Walker	**Telephone:**	
Contract Period of Performance:	**From:** 3/18/81 **To:** 2/28/82		
Project/Area/Task:			
Contract Funding:	FY81 $51,575 FY $	FY $	FY $
Cumulative Funding To Date:	$51,575		

Contract objectives are to perform maintenance service on the Natural Bridges National Monument 100-kWp Solar PV System, train National Park Service personnel and local subcontractor, and assist in completion of maintenance documentation.

During FY 1981 a repeat of the site acceptance test was completed with NPS and the maintenance subcontractor for training purposes. A system maintenance manual is being prepared which will be published during FY 1982. Replacement spare parts were ordered for the main inverter. Sandia National Laboratories will administer a follow-on to this contract.

Title:	Services Connected with the Performance of Solar Photovoltaic System Design, Installation and Evaluation	**Contract Number:**	BX-547
Directing Organization:	MIT Lincoln Laboratory		
Project Engineer:	M. C. Russell	**Telephone:**	(617) 862-5500 x 5364
Contractor:	University of Hawaii at Manoa Hawaii Natural Energy Institute Honolulu, HI 96822		
Principal Investigator:		**Telephone:**	
Contract Period of Performance:	**From:** 6/24/80 **To:** 5/31/82		
Project/Area/Task:	Innovative Photovoltaic Applications for Residences		
Contract Funding:	FY80 $100,000 FY81 $185,264	FY $	FY $
Cumulative Funding To Date:	$285,264		

This Innovative Photovoltaic Applications for Residences project entails the installation of three residential PV systems involving three retrofit designs.

Support of data acquisition activities for this project will continue through May 1982.

Title:	Data Acquisition/ Reduction System	**Contract Number:**	BX-691
Directing Organization:	MIT Lincoln Laboratory		
Project Engineer:	B. E. Nichols	**Telephone:**	(617) 862-5500 x 234
Contractor:	Hewlett-Packard Co. 32 Hartwell Avenue Lexington, MA 02173		
Principal Investigator:	E. Duffy	**Telephone:**	
Contract Period of Performance:	**From:** 2/10/81 **To:** 4/17/81		
Project/Area/Task:	Southwest Residential Experiment Station		
Contract Funding:	FY81 $57,643 FY $ FY $ FY $		
Cumulative Funding To Date:	$57,643		

This equipment is part of the Residential Data System at the Southwest Residential Experiment Station.

Installation was completed in the third quarter of FY 1981. Residential Data System is operational.

Title:	Design, Installation, and Evaluation of a Solar Photovoltaic System	**Contract Number:**	BX-542
Directing Organization:	MIT Lincoln Laboratory		
Project Engineer:	M. C. Russell	**Telephone:**	(617) 862-5500 x 5364
Contractor:	J. F. Long Properties Phoenix, AZ		
Principal Investigator:	J. F. Long	**Telephone:**	
Contract Period of Performance:	**From:** 5/30/80 **To:** 6/30/81		
Project/Area/Task:	Innovative Photovoltaic Applications for Residences (IPARs)		
Contract Funding:	FY80 $200,000 FY81 $60,499 FY $ FY $		
Cumulative Funding To Date:	$260,499		

This IPAR project involves the installation and evaluation of an experimental PV-powered residence of new construction.

This project was to be completed on March 31, 1981. Subsequently a three-month extension was requested to complete the final report. As of October 15, 1981, the report has not been delivered.

Sandia National Laboratory will be responsible for any follow-on work to evaluate this system.

Title: Residential Energy Studies | **Contract Number:** BX-561
Directing Organization: MIT Lincoln Laboratory
Project Engineer: E. C. Kern | **Telephone:** (617) 862-5500 x 7855
Contractor: MIT Energy Laboratory
77 Massachusetts Ave. Rm. E19-702
Cambridge, MA 02139
Principal Investigator: P. Powell | **Telephone:**
Contract Period of Performance: **From:** 5/22/80 **To:** 11/30/81
Project/Area/Task: Residential System Studies
Contract Funding: FY80 $105,000 FY81 $145,000 FY $ FY $
Cumulative Funding To Date: $250,000

Research studies are directed at the potential for retrofit systems, the characteristics of the residential PV markets, and the relative work of various PV systems to homeowners.

Carryover FY 1981 funding will support conclusion of these studies and publication of a summary document.

Title: Sensor Box Assembly | **Contract Number:** CX-3239
Directing Organization: MIT Lincoln Laboratory
Project Engineer: B. E. Nichols | **Telephone:** (617) 862-5500 x 234
Contractor: Mutron Corp.
646 Summer Street
Brockton, MA 02402
Principal Investigator: A. Largey | **Telephone:**
Contract Period of Performance: **From:** 1/26/81 **To:** 4/1/81
Project/Area/Task: Southwest Residential Experiment Station
Contract Funding: FY81 $15,170 FY $ FY $ FY $
Cumulative Funding To Date: $15,170

This equipment is part of the Residential Data System installed at the Southwest Residential Experiment Station.

Installation was completed in the third quarter of FY 1981. Residential Data System is operational.

Title: Data Acquisition Control Assembly
Contract Number: CX-3313
Directing Organization: MIT Lincoln Laboratory
Project Engineer: B. E. Nichols
Telephone: (617) 862-5500 x 234
Contractor: Mutron Corporation
646 Summer Street
Brockton, MA 02101
Principal Investigator: A. Largey
Telephone:
Contract Period of Performance: From: 4/7/81 To: 7/15/81
Project/Area/Task: Southwest Residential Experiment Station
Contract Funding: FY81 $27,564 FY $ FY $ FY $
Cumulative Funding To Date: $27,564

This equipment is part of the Residential Data System at the Southwest Residential Experiment Station.

Installation was completed in the third quarter of FY 1981. Residential Data System is operational.

Title: Data Concentrator Unit
Contract Number: CX-3314
Directing Organization: MIT Lincoln Laboratory
Project Engineer: B. E. Nichols
Telephone: (617) 862-5500 x 234
Contractor: Mutron Corporation
646 Summer Street
Brockton, MA 02402
Principal Investigator: A. Largey
Telephone:
Contract Period of Performance: From: 3/18/81 To: 5/1/81
Project/Area/Task: Southwest Residential Experiment Station
Contract Funding: FY81 $30,534 FY $ FY $ FY $
Cumulative Funding To Date: $30,534

This equipment is part of the Residential Data System at the Southwest Residential Experiment Station.

Installation was completed in the third quarter of FY 1981. Residential Data System is operational.

Title:	Operation and Maintenance of Photovoltaic Powered Irrigation Experiment	**Contract Number:**	BX-192
Directing Organization:	MIT Lincoln Laboratory		
Project Engineer:	B. E. Nichols	**Telephone:**	(617) 862-5500 x 234
Contractor:	University of Nebraska-Lincoln Lincoln, NE 68503		
Principal Investigator:	P. E. Fischback	**Telephone:**	(404) 472-1626
Contract Period of Performance:	**From:** 7/1/77 **To:** 12/31/81		
Project/Area/Task:			
Contract Funding:	FY77 $114,258 FY78 $134,824 FY79 $123,085 FY80 $65,000		
Contract Funding:	FY81 $30,500		
Cumulative Funding To Date:	$467,667		

Contract objectives include operation and maintenance of the 25-kWp solar PV experiment to demonstrate the application to crop irrigation, as well as to secondary agricultural uses, such as crop drying and nitrogen manufacturing.

Battery life and module failure studies continued during FY 1981. The irrigation system pumped 15,310,000 gallons in July; 9,597 gallons in August with the array and 20 hp dc motor. Tours are conducted with much interest. The site is being incorporated into the UN-L total energy farm which is in the construction phase presently. Future support of this experiment will be transferred to Sandia National Laboratories.

Title:	Operation of the Southwest Residential Experiment Station	**Contract Number:**	BX-554
Directing Organization:	MIT Lincoln Laboratory		
Project Engineer:	J. W. Harrill	**Telephone:**	(617) 862-5500 x 7974
Contractor:	New Mexico Solar Energy Institute New Mexico State University Box 3SOL Las Cruces, NM 88003		
Principal Investigator:	H. S. Zwibel	**Telephone:**	
Contract Period of Performance:	**From:** 10/1/80 **To:** 9/30/82		
Project/Area/Task:	Southwest Residential Experiment Station		
Contract Funding:	FY80 $171,027 FY81 $2,987,328 FY82 $447,301 FY $		
Cumulative Funding To Date:	$3,605,656		

The objective of this activity is to provide a common site in the southwestern United States for the operation and assessment of experimental residential PV power systems. Regionally appropriate prototype systems were procured for testing, evaluating, and refining residential PV power systems prior to installation in occupied residences.

During FY 1981, site development activity was completed and eight prototype systems were activated. FY 1982 funding will provide continued operation of the Southwest Residential Experiment Station including evaluation of the eight prototype systems. Future support of this activity will be transferred to Sandia National Laboratories.

Title: Monitored Residence Data Acquisition Control Assembly
Contract Number: CX-3257
Directing Organization: MIT Lincoln Laboratory
Project Engineer: B. E. Nichols
Telephone: (617) 862-5500 x 234
Contractor: Peerless Instruments Co.
90-15 Corona Avenue
Elmhurst, NY 11373
Principal Investigator: H. Kneissl
Telephone:
Contract Period of Performance: **From:** 2/4/81 **To:** 4/30/81
Project/Area/Task: Southwest Residential Experiment Station
Contract Funding: FY81 $29,000 FY $ FY $ FY $
Cumulative Funding To Date: $29,000

This equipment is part of the Residential Data System at the Southwest Residential Experiment Station.

Installation was completed in the third quarter of FY 1981. Residential Data System is operational.

Title: Magnetic Tape Transport Units
Contract Number: CX-3250
Directing Organization: MIT Lincoln Laboratory
Project Engineer: H. A. Fenton
Telephone: (617) 862-5500 x 5561
Contractor: Peripheral Systems, Inc.
c/o J & J Associates
225 East Street
Winchester, Massachusetts 01890
Principal Investigator: K. Incorvati
Telephone:
Contract Period of Performance: **From:** 1/28/81 **To:** 3/15/81
Project/Area/Task: Southwest Residential Experiment Station
Contract Funding: FY81 $25,600 FY $ FY $ FY $
Cumulative Funding To Date: $25,600

This data recording equipment is part of the Residential Data System at the Southwest Residential Experiment Station.

Installation completed in third quarter FY 1981. Residential Data System operational.

Title: Development of Safety Standard for Utility-Interactive Inverters
Contract Number: BX-707
Directing Organization: MIT Lincoln Laboratory
Project Engineer: C. H. Cox
Telephone: (617) 862-5500 x 5862
Contractor: Underwriters Laboratories
Northbrook, IL
Principal Investigator: W. J. Christian
Telephone:
Contract Period of Performance: **From:** 5/14/81 **To:** 3/8/82
Project/Area/Task: Residential Power Conditioning Technology Development
Contract Funding: FY81 $76,842 FY $ FY $ FY $
Cumulative Funding To Date: $76,842

This work will result in the development of a proposed safety standard covering utility-interactive power conditioners.

Carryover FY 1981 funding will support conclusion of these studies and publication of a summary document.

Title: The Development of Line Commutated Inverters
Contract Number: BX-712
Directing Organization: MIT Lincoln Laboratory
Project Engineer: C. H. Cox
Telephone: (617) 862-5500 x 5862
Contractor: Windworks, Inc.
Route 3, Box 44A
Mukwonago, WI 53149
Principal Investigator: D. A. Sears
Telephone:
Contract Period of Performance: **From:** 3/25/81 **To:** 11/30/81
Project/Area/Task: Power Conditioning Technology Development
Contract Funding: FY81 $63,622 FY $ FY $ FY $
Cumulative Funding To Date: $63,622

This work is directed toward improving the power factor and reducing the harmonics of utility interactive line commutated inverters.

Design is complete; breadboard construction is in progress. Pending evaluation results, a modified line commutated inverter will be procured during FY 1982.

NASA/Lewis Research Center

Title:	Stand-Alone Applications Project Support
Contract Number:	C-42701-D
Directing Organization:	NASA Lewis Research Center
Project Engineer:	William A. Brainard
Telephone:	(216) 433-4000 ext 5255
Contractor:	The Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009
Principal Investigator:	Barry Siegel
Telephone:	(213) 648-7126
Contract Period of Performance:	**From:** 3/80 **To:** 4/82
Project/Area/Task:	Test and Applications
Contract Funding:	FY80 $140,000 FY81 $60,000 FY $ FY $
Cumulative Funding To Date:	$200,000

Contract objective is to provide support to the project office for report preparation, technical and cost analyses, and planning on a task order basis.

On-going task PV-8 provides capital and life cycle cost analysis for diesel augmented PV system based on Schuchuli system configuration and load profile.

Title:	Solar Technology Development Support
Contract Number:	EY-76-C-06-1830
Directing Organization:	NASA Lewis Research Center
Project Engineer:	John Bozek
Telephone:	(216) 433-4000 ext. 216
Contractor:	Battelle-Pacific Northwest Laboratory Battelle Boulevard Richland, VA 99353
Principal Investigator:	Raymond Watts
Telephone:	(509) 376-4348
Contract Period of Performance:	**From:** 7/81 **To:** 3/82
Project/Area/Task:	Test and Applications
Contract Funding:	FY81 $30,000 FY $ FY $ FY $
Cumulative Funding To Date:	$30,000

Contract objective includes analysis of data gathered to define the nature and extent of the domestic and international solar industry and review of strategies for improving the U.S. solar industry stance.

Title:	Market Assessment of PV Energy Systems for Agricultural Applications in Developing Countries — **Contract Number:** DEN 3-180
Directing Organization:	NASA Lewis Research Center
Project Engineer:	William A. Brainard — **Telephone:** (216) 433-4000 ext. 5255
Contractor:	Donovan, Hamester & Rattien, Inc. 1055 Thomas Jefferson St., N.W. Washington, DC 20007
Principal Investigator:	Dr. Anil Cabraal — **Telephone:** (202) 342-5400
Contract Period of Performance:	**From:** 11/79 **To:** 11/81
Project/Area/Task:	Test and Applications
Contract Funding:	FY80 $339,162 FY81 $110,196 FY $ FY $
Cumulative Funding To Date:	$449,358

The study is to provide an assessment of the potential international market for photovoltaic products in the agricultural sector in the near- and mid-term. In-depth studies of several countries representative of regions of the world are conducted to provide a base line for extrapolating to the world-wide market.

Phase I assessment identified five countries for in-depth studies. In-country visits to the Philippines, Mexico, Morocco, Nigeria, and Colombia were completed. Country specific marketing reports for Philippines and Mexico were published. Reports for Morocco, Nigeria, and Colombia are in publication process. Final world-wide assessment report is in draft.

Title:	Market Assessment of PV Energy Systems for Cottage Industry Applications in Developing Countries — **Contract Number:** DEN 3-197
Directing Organization:	NASA Lewis Research Center
Project Engineer:	William A. Brainard — **Telephone:** (216) 433-4000 ext. 5255
Contractor:	IIT Research Institute 10 W. 35th Street Chicago, IL 60616
Principal Investigator:	Therese Philippi — **Telephone:** (312) 567-4000
Contract Period of Performance:	**From:** 5/80 **To:** 11/81
Project/Area/Task:	Tests and Applications
Contract Funding:	FY80 $322,812 FY $ FY $ FY $
Cumulative Funding To Date:	$322,812

The study is to provide an assessment of the potential international market for photovoltaic products in small-scale rural industries in the near- and mid-term. In-depth studies of several countries representative of regions of the world are conducted to provide a baseline for extrapolating to the world-wide market.

Phase I study effort determined the energy requirement and characteristics of cottage industries and identified candidate countries for in-depth studies. Data obtained from in-country visits to Philippines and Mexico supported Phase I findings that cottage industries will not provide a significant market for photovoltaics in the near- or mid-term. Therefore a partial termination of the contract was issued and a final report is being prepared to document the study findings.

Title:	Photovoltaic Stand-Alone Systems Design Handbook	**Contract Number:**	DEN 3-195
Directing Organization:	NASA Lewis Research Center		
Project Engineer:	Thomas M. Klucher	**Telephone:**	(216) 433-4000 ext 5255
Contractor:	Monegon, Ltd. 4 Professional Drive Suite 130 Gaithersburg, MD 20760		
Principal Investigator:	Harold Macomber	**Telephone:**	(301) 258-7540
Contract Period of Performance:	**From:** 4-80 **To:** 7-81		
Project/Area/Task:	Systems Development and Engineering		
Contract Funding:	FY79 $69,500 FY80 $-0-	FY81 $9,999	FY $
Cumulative Funding To Date:	$79,499		

Contract objective is to develop a concise, self-contained photovoltaic design handbook for stand-alone systems. The handbook shall be educational in nature, suitable for use by applications engineers inexperienced with photovoltaic systems, and shall contain sufficient design and application information to enable users to easily establish initial sizing, configurations, and design approaches in photovoltaic systems.

The handbook entitled "Photovoltaic Stand-Alone Systems - Preliminary Engineering Design Handbook" was published in September 1981. Report Number is NASA CR-165352.

Title:	Modular Photovoltaic Stand-Alone Systems	**Contract Number:**	DEN 3-207
Directing Organization:	NASA Lewis Research Center		
Project Engineer:	Thomas M. Klucher	**Telephone:**	(216) 433-4000 ext 5255
Contractor:	Hughes Aircraft Company P.O. Box 90515 Los Angeles, CA 90009		
Principal Investigator:	George J. Naff	**Telephone:**	(213) 670-1515 ext 6864
Contract Period of Performance:	**From:** 11-24-80 **To:** 11-24-82		
Project/Area/Task:	Systems Development and Engineering		
Contract Funding:	FY79 $290 K FY80 $170 K	FY $	FY $
Cumulative Funding To Date:	$460 K		

The primary objective is to develop a family of modular stand-alone power systems that covers the range in power level from 1 kW to 15 kW and is easily adaptable to different environments and applications, reliable, and low cost. A secondary objective is to compile, evaluate, and determine technology options associated with the balance of stand-alone systems.

Contract is on schedule. Balance of system technology options have been assessed; conceptual and preliminary designs of modular systems have been developed.

Title:	Solar Photovoltaic Powered Refrigerator Freezers for Medical Use in Remote Geographic Locations	**Contract Number:**	DEN 3-240
Directing Organization:	NASA Lewis Research Center		
Project Engineer:	Larry Thaler	**Telephone:**	(216) 433-4000 ext 305
Contractor:	Motorola, Inc. Semiconductor Group 5005 East McDowell Road Phoenix, AZ 85008		
Principal Investigator:	Ray White	**Telephone:**	244-6367
Contract Period of Performance:	**From:** 3-19-81 **To:** 9-19-81		
Project/Area/Task:	Test and Applications		
Contract Funding:	FY81 $39,260 FY $	FY $	FY $
Cumulative Funding To Date:	$39,260		

Contract objectives are to design and fabricate a PV R/F system that will function according to WHO specifications in remote medical posts.

Prototype undergoing modification September 1981.

Department of Energy
Albuquerque Operations Office

Title: Acurex PRDA 35 PV Experiment

Contract Number: DE-AC04-79ET20623

Directing Organization: U. S. Department of Energy - Albuquerque Operations Office

Project Engineer: D. C. Graves **Telephone:** (505) 846-5202

Contractor: Acurex Corporation
Alternate Energy Division
485 Clyde Ave.
Mountain View, CA 94042

Principal Investigator: D. Rafinejad **Telephone:** (415) 964-3200, x 3534

Contract Period of Performance: **From:** 09-28-79 **To:** 09-30-83

Project/Area/Task: Array Design and Evaluation

Contract Funding: FY79 $1,164,443 FY80 $204,484 FY81 $422,315 FY $

Cumulative Funding To Date: $1,791,242

Contract objectives are to design and install a 35-kW parabolic trough type concentrating domestic hot water system to the G. N. Wilcox Hospital in Lihue, Kauai, HI.

System 85% complete. Seeking solutions to: (1) inverter failure to stay parallel with grid and (2) bubbles forming in PVB bonding agent between PV cells and glass superstrate.

Title: Phoenix Airport Project PRDA 35

Contract Number: DE-AC04-80ET 20624

Directing Organization: U. S. Department of Energy - Albuquerque Operations Office

Project Engineer: E. A. Walker **Telephone:** (505) 846-5209

Contractor: Arizona Public Service Company
P. O. Box 21666
Phoenix, AZ 85036

Principal Investigator: Joe McGuirk **Telephone:** (602) 271-2431

Contract Period of Performance: **From:** 03-19-80 **To:** 06-30-82

Project/Area/Task: Array Design and Evaluation

Contract Funding: FY80 $3,088,176 FY81 $3,412,877 FY $ FY $

Cumulative Funding To Date: $6,501,053

The APs project will demonstrate the use of a passively cooled point focus concentrator utilizing two-axis tracking. The array will produce 225-kWp electrical power from 80 Martin Marietta arrays.

CPR held 25 November 1980. Motorola replaced by Martin Marietta as array supplier. Martin Marietta cell assembly begun October 1, 1981.

Title:	BDM Corporation Office Building Project PRDA 35	**Contract Number:**	DE-AC04-79ET20625
Directing Organization:	U.S. Department of Energy - Albuquerque Operations Office		
Project Engineer:	E. A. Walker	**Telephone:**	(505) 846-5209
Contractor:	BDM Corporation 1801 Randolph Road, S.E. Albuquerque, NM 87106		
Principal Investigator:	Wayne Kauffman	**Telephone:**	(505) 848-5359
Contract Period of Performance:	**From:** 09-28-79 **To:** 12-15-83		
Project/Area/Task:	Array Design and Evaluation		
Contract Funding:	FY79 $1,111,421 FY80 $-0-	FY81 $550,219	FY $
Cumulative Funding To Date:	$1,661,640		

Contract objective is to demonstrate the use of a roof-mounted concentrator system to provide both electrical and thermal energy to a commercial building. The peak power is 47 kW electrical and 8 million Btu/day thermal. For safety reasons electrical flow to the utility is allowed only on special occasions. The array is 9 rows of Solar Kinetics parabolic troughs with PV receivers supplied by Applied Solar Energy Corporation.

- Critical Project Review - June 4, 1981.
- Site preparation complete October 1981.
- Module production started October 1981.

Title:	Dallas/Fort Worth Airport Project PRDA-35	**Contract Number:**	DE-AC04-79ET20626
Directing Organization:	U. S. Department of Energy - Albuquerque Operations Office		
Project Engineer:	E. A. Walker	**Telephone:**	(505) 846-5209
Contractor:	E-Systems Energy Technology Center P. O. Box 6118 Dallas, TX 75222		
Principal Investigator:	Dennis Yakel	**Telephone:**	(214) 272-0515
Contract Period of Performance:	**From:** 09-28-81 **To:** 01-31-82		
Project/Area/Task:	Array Design and Evaluation		
Contract Funding:	FY79 $665,984 FY80 $118,568	FY81 $345,572	FY $
Cumulative Funding To Date:	$1,130,124		

This system is intended to demonstrate the use of both electrical and thermal energy derived from a linear concentrating PV array. Electricity will power lights and small motors in the utility plant, while the thermal portion will preheat boiler feed water. About 60% of the available direct normal insolation will be utilized.

FY 1981 was spent primarily in materials procurement and in placing subcontracts for the solar cell/receivers and installation work.

Title: Lovington Photovoltaic Flat Panel Facility - PRDA 38
Contract Number: DE-AC04-79ET-20628
Directing Organization: U.S. Department of Energy - Albuquerque Operations Office
Project Engineer: Dean C. Graves **Telephone:** (505) 846-5202
Contractor: Lea County Electric Cooperative, Inc.
P. O. Drawer 1447
Lovington, NM 88260
Principal Investigator: E. R. Felfe **Telephone:** (505) 396-3631
Contract Period of Performance: **From:** 09-30-79 **To:** 05-19-83
Project/Area/Task: Array Design and Evaluation
Contract Funding: FY79 $904,829 FY80 $1,758,529 FY81 $220,738 FY $
Cumulative Funding To Date: $2,884,096

Contract objectives are to design, assemble, and install a nominal 100-kW photovoltaic experiment and to operate the system for a period of two years.

The system became operational on March 17, 1981, and was dedicated on May 5, 1981. A phase III operations and maintenance contract is in place and the system is currently operating.

Title: New Mexico Solar Energy/El Paso Electric Project PRDA 38
Contract Number: DE-AC04-79ET20629 & DE-AC04-81 AL17093
Directing Organization: U. S. Department of Energy - Albuquerque Operations Office
Project Engineer: E. A. Walker **Telephone:** (505) 846-5209
Contractor: Regents of New Mexico State University
Box 3699
Las Cruces, NM 88003
Principal Investigator: Vernon Risser **Telephone:** (505) 646-4245
Contract Period of Performance: **From:** 09-27-79 **To:** 06-01-83
Project/Area/Task: Array Design & Evaluation
Contract Funding: FY79 $252,144 FY80 $218,726 FY81 $233,082 FY $
Cumulative Funding To Date: $703,952

Contract objectives are to install and operate a 20-kW (reduced to 18 kW during design) photovoltaic system to support DC loads at the El Paso Electric Company's Newman Power Station.

The system has been operational since December 1980. It was finished on schedule and under cost. The nominal power output is around 16 kW and the system has generated a high of 23 kW. The system has generated approximately 20,000 kWh to date.

Title:	SAI-Science and Art Center/ Oklahoma City Project PRDA 38	**Contract Number:**	DE-AC04-79ET20630
Directing Organization:	U.S. Department of Energy - Albuquerque Operations Office		
Project Engineer:	E. A. Walker	**Telephone:**	(505) 846-5209
Contractor:	Science Applications, Inc. 8400 Westpark Drive McLean, VA 22101		
Principal Investigator:	Y. R. Gupta	**Telephone:**	(703) 827-4783
Contract Period of Performance:	**From:** 09-28-79 **To:** 01-31-82		
Project/Area/Task:	Array Design and Evaluation		
Contract Funding:	FY79 $852,558 FY80 $1,664,354 FY $ FY $		
Cumulative Funding To Date:	$2,516,912		

Contract objectives are to install and operate a 135-kW power system using a mirror-enhanced flat-plate photovoltaic array at the Oklahoma Center for Science and Art. Power will be used at the center with excess being sold to Oklahoma Gas & Electric Co.

This project was to have been operational in late summer 1981. Inability of Solarex to support module delivery and failure of SAI to negotiate PCU order in time caused slip to January 1982. Site work will be restarted in late October after a three-month hold to get remaining hardware. Project should meet operational goals with some small cost overrun.

Title:	Beverly High School PRDA 38 Photovoltaic Project	**Contract Number:**	DE-AC04-79ET20631
Directing Organization:	U. S. Department of Energy - Albuquerque Operations Office		
Project Engineer:	D. C. Graves	**Telephone:**	(505) 846-5202
Contractor:	Solar Power Corporation 20 Cabot Road Woburn, MA 01801		
Principal Investigator:	Dr. R. Addiss	**Telephone:**	(617) 935-4600
Contract Period of Performance:	**From:** 09-28-79 **To:** 09-30-83		
Project/Area/Task:	Array Design and Evaluation		
Contract Funding:	FY79 $919,339 FY80 $1,827,949 FY81 $376,266 FY $		
Cumulative Funding To Date:	$3,123,554		

Contract objectives are to build and operate a 100-kW flat-plate photovoltaic system to supply electric power to the Beverly High School/C. H. Palton Vocational School. The PV system will supply a significant portion of the annual electric demand and is a good match to the load profile. Student participation is encouraged. System level experience will be gained in operating the facility, selling power to the local utility and in maintaining the system.

Project dedicated April 13, 1981. Phase II final report is in preparation. Phase III period of performance is November 30, 1981, through November 30, 1983.

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