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PHOTOVOLTAIC SYSTEMS

Program Summary

Prepared for the U.S. Department of Energy
Assistant Secretary for Energy Technology
Office of Solar, Geothermal, Electric and Storage Systems

December 1978

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Preface

On October 26, 1974, the Solar Energy Research, Development and Demonstration Act (Public Law 93-473) was signed into law, authorizing a vigorous Federal program of research, development, and demonstration. Its goal was to provide the nation with the option of using solar energy as a new source for meeting future requirements. In response to the mandates of this act, major efforts were made within the Division of Solar Energy of the Energy Research and Development Administration (ERDA) to expeditiously develop and introduce economically competitive and environmentally acceptable solar energy systems.

These responsibilities were transferred to the newly organized U.S. Department of Energy (DOE) on October 1, 1977. Presently DOE's solar energy activities are divided into three distinct organizational components:

- Division of Central Solar Technology
 - Ocean Systems Program
 - Solar Thermal Power Systems Program
- Division of Distributed Solar Technology
 - Biomass Energy Systems Program
 - Photovoltaic Systems Program
 - Wind Energy Systems Program
- Division of Solar Applications
 - Heating and Cooling of Buildings Program
 - Agriculture and Industrial Process Heat Program
 - Technology Transfer Program

Both the Division of Central Solar Technology and the Division of Distributed Solar Technology come under the jurisdiction of the Office of Assistant Secretary for Energy

Technology (SOLAR/ET), while the Division of Solar Applications comes under the jurisdiction of the Office of the Assistant Secretary for Conservation and Solar Applications (SOLAR/CS). An overview of the current DOE solar program organization is shown in Figure 1.

Program planning continues under the guidelines established by PL 93-473 and by three other legislative acts passed by the 93rd Congress: the Solar Heating and Cooling Demonstration Act of 1974 (PL 93-409), the Energy Reorganization Act of 1974 (PL 93-438), and the Federal Nonnuclear Energy Research and Development Act of 1974 (PL 93-577). Together these four laws grant DOE and other Federal agencies the authority to pursue a research program aimed at effective solar energy use. Under this authority, SOLAR/CS and SOLAR/ET are working to develop solar energy technologies and to complement efforts in the private sector to develop solar energy resources.

A program summary is issued for each solar program annually. Each summary provides an overview of the ongoing research, development, and demonstration efforts of the preceding fiscal year (FY).

This program summary describes each of the DOE's Photovoltaic Systems Program projects funded and/or in existence during fiscal year 1978 (October 1, 1977 through September 30, 1978) and reflects their status as of September 30, 1978. This document is a follow-up to the FY 1977 Photovoltaic Program Summary (DOE/ET0019/1) published in January 1978 which can be ordered from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Figure 1. DOE Solar Program Organization

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INTRODUCTION

Photovoltaic conversion is one of eight solar energy technologies being developed by the Department of Energy. These technologies were selected for development because they were viewed as viable alternatives for providing substantial energy to the nation and reducing dependence on fossil fuels.

The activities of the Photovoltaic Systems Program during fiscal year 1978 are summarized in this report. Accomplishments are cited and projects are summarized to provide an overview of the program.

THE PHOTOVOLTAIC PHENOMENON

Photovoltaic energy systems provide a clean, simple method for direct conversion of sunlight to electrical energy. Photovoltaic systems require no complex machinery, heat engine cycle, or intermediate conversion to heat; in addition, photovoltaic systems are silent. Since they are intrinsically modular, photovoltaic systems are potentially cost effective on a small scale (see Figure 2). Photovoltaic devices provide a way of converting light directly into electricity. When light energy or photons strike certain materials called semiconductors, internal voltages are created. In devices specially designed for the purpose, wires may be attached and electricity drawn off. Light meters used in photography employ this principle to measure the intensity of light by having the electricity move a needle across a scale. On space satellites, numbers of these photovoltaic devices, called solar cells, are wired together to provide electric power from sunlight. The basic scientific principles are well known, and the technology for specialized uses is relatively advanced. Arrays of photovoltaic cells can be connected in series and parallel to adjust the voltage and current. Photovoltaic conversion has not, however, attained wide usage due to the high cost of manufacturing the photovoltaic devices and other

system components. The Photovoltaic Systems Program will encourage increases in the annual production rate of arrays to the order of 20 peak megawatts (MW) in 1982. The Program assumes that photovoltaic systems will be economically viable in 1986 for a wide variety of applications. By 1990, it is expected that energy from photovoltaic systems should be cost effective for utility applications.

Solar photovoltaic conversion systems were first used extensively in the U.S. space program; these systems had a maximum capacity of 10 kilowatts. The basic photovoltaic conversion technology has been proven, and terrestrial applications of solar systems already exist.

Photovoltaic systems may be used to generate power in large central stations for sale to customers, or in decentralized systems in which the consumers produce the power themselves. Electricity generated in this manner can be used immediately for direct current (DC) loads in many decentralized applications. It may be inverted to conventional alternating current (AC) either by centralized or decentralized generation facilities, or stored, without inversion, for subsequent AC or DC load use. Also, interactive systems are under study in which the consumers purchase power when needed from the utility and sell back power during excess production.

Figure 3 depicts schematically the basic components of a simple photovoltaic system.

A small-scale photovoltaic industry now exists in the United States. It consists of ten manufacturers of single-crystal silicon solar arrays and two pilot production lines for cadmium sulfide (CdS) arrays. At least one manufacturing facility recently has been automated with a production capability of approximately 2 MW per year. Depending

Figure 2. Arrays of Photovoltaic Cells in Various Configurations

Figure 3. Photovoltaic System

on the quantity of arrays purchased, the silicon solar arrays currently range from \$10 to \$30 per peak watt. At this price level, annual demand for photovoltaic systems is limited to 1 to 2 MW. Expansion of photovoltaic applications can furnish a significant contribution to the nation's energy needs if certain technical questions can be resolved and system costs reduced. These questions relate to reliability, operational performance, and maintenance requirements. Array prices must be reduced by a factor of 25 from current levels of \$12 to \$.50 per peak Watt (Wp); system costs must be reduced by

a factor of 20 in order to compete with the conventional energy systems and achieve broad commercial application.

High costs, limited demand, and industry capacity form an internally reinforcing set of conditions in opposition to widespread use of this technology. An aggressive Federal research, development, and test program is working toward reducing the cost of photovoltaic systems and stimulating applications which will accelerate production capacity growth.

The Photovoltaic Systems Program

The Photovoltaic Systems Program is designed to expand as rapidly as possible the commercial use of photovoltaic systems, through a program of research, process development in support of the manufacturing industry, tests, and applications.

GOALS AND OBJECTIVES

The overall objective of the photovoltaic program is to ensure that photovoltaic conversion systems play a significant role in supplying energy to the nation by the year 2000, providing approximately 50 gigawatts electric (GWe) of generating capacity.

In order to achieve this overall objective, several time-phased program goals have been defined. (All goals are expressed in terms of 1975 costs.)

- Near Term:
To achieve photovoltaic array prices of \$1-2/peak watts at an annual production rate of 20 peak megawatts in 1982. At this price level, energy costs should range from 100 to 200 mills/kWhr, compared to the production cost of 40-60 mills/kWhr in today's fossil-fueled intermediate capacity plants.
- Mid Term:
To achieve photovoltaic array prices of \$0.50 per peak watt, and an annual production rate of 500 peak megawatts in 1986. At this price level, energy costs should be in the range of 50 to 80 mills/kWhr. Mission studies indicate that residential uses will be cost effective at this time.
- Far Term:
To achieve an array price goal of \$0.10 to \$0.30 per peak watt in 1990, and an annual production rate of 50 peak GWe in the year 2000. At this price range, energy costs should be in the range of 40 to 60 mills/kWhr and

should be cost effective for utility applications.

It is anticipated that achievement of these goals will make photovoltaic systems economically competitive with alternative energy sources for dispersed on-site applications as well as for central power generation. Intermediate year goals for annual production, array, and system costs have been established to permit assessment of program progress.

STRATEGY

The overall strategy of the Photovoltaic Systems Program places primary emphasis on commercial readiness for photovoltaic systems through a series of highly visible, load center experiments such as residential, commercial, and agricultural applications. In addition, a concerted research and development effort is being conducted in pursuit of significant improvements in system performance-to-cost ratios. Specifically, the strategy calls for:

- Early applications of photovoltaic systems selected from industry/user proposals. Initial applications are in the 20 to 500 kWe range.
- Parallel pursuit of technologies having potential for significant array price reductions. These include the Low-Cost Solar Array (LSA), concentrator arrays, and advanced material/thin-film devices.
- Acceleration of private market sales to stimulate commercialization.

Early applications of photovoltaic systems are being implemented to develop information on operational costs, reliability, and performance and to acquaint potential customers with the characteristics and feasibility of such systems. Large-scale experiments will be installed to:

- Address technical questions relating

to systems integration, performance, reliability, and maintenance;

- Gather data on photovoltaic systems energy costs; and
- Identify potential legal or institutional barriers.

Applications of increasing complexity will be implemented later to:

- Incorporate technology advances from the ongoing research and development effort;
- Provide potential users with system design, construction, and operational experience; and
- Stimulate a growing market for photovoltaic arrays thus encouraging industry growth.

Various incentives will be considered to encourage private commitments of capital, both for production and application facilities in advance of the achievement of cost effectiveness for photovoltaic systems. These incentives will be assessed in terms of cost and market impact.

The Photovoltaic Systems Program is committed to:

- Obtaining large-scale operating experience in photovoltaic system applications;
- Improving the efficiency of cells and manufacturing process;
- Coordinating with the storage technology program to augment photovoltaic system operations; and
- Improving cell and array reliability and lifetime.

During the past four years, the Photovoltaic Systems Program effort has contributed to significant cost reductions associated with silicon arrays. Today's cost of silicon arrays is approximately 20 percent of array cost of 1974 for products that are superior in reliability, efficiency, and ruggedness. These significant cost improvements are the result

of the intensive effort applied to improving processes used to produce suitable quantities of quality silicon wafers as well as advances in many of the array manufacturing processes. Further cost reductions have been identified as being feasible, particularly in silicon materials, silicon area production, and silicon array manufacture. It is expected that silicon material may be produced in the near future for 20 percent of today's cost.

Increased procurement of arrays is expected to result in reduced unit costs (see Figure 4). As indicated, array costs in 1980 will be only 10 percent of the cost of devices used in past space applications. The aggressive technology development underway will identify concepts by 1980 that are most attractive for meeting both mid-term and far-term needs.

PROGRAM ELEMENTS

The objectives of the program are accomplished through a series of program element efforts:

- Program Assessment and Integration
- Research and Advanced Development
- Technology Development
- System Definition and Development
- System Application Experiments
- Standards and Performance Criteria

The Program Assessment and Integration element addresses the key issues facing the entire Photovoltaic Program. These issues relate to technology, production, and applications. Several efforts are undertaken in addressing these issues:

- Economic analyses are performed to characterize the potential costs for photovoltaic systems, as well as examination of methods of introducing photovoltaic systems into the market.
- Policy and planning studies are con-

Figure 4. Terrestrial Solar Array Price History Goals

ducted to provide strategies for accelerating commercialization of photovoltaic energy systems.

The Research and Advanced Development (R&AD) element is directed toward achieving near-term payoffs from silicon arrays, concentrator systems, and other known photovoltaic materials. This effort includes:

- Near-term R&AD, especially in the area of developing selected thin-film cells using materials such as cadmium sulfide, amorphous silicon, polycrystalline silicon, and gallium arsenide (efforts are also directed toward improvements in cell efficiency);
- Novel, high-risk concepts, including identifying new materials, devices or processing concepts;
- Long-term research to identify promising new materials and concepts that may be suitable for advanced development beyond 1981; and
- Fundamental support research which investigates properties of materials, photovoltaic device and cell physical mechanisms, and advanced measurement techniques.

The Technology Development element concerns the achievement of substantial reductions in the cost of photovoltaic cells, arrays, and systems. These cost reductions are achievable by pursuing various technical options, and accelerating the development of these options. The options currently being pursued are:

- Low-cost silicon solar arrays, which are flat-plate arrays using the highly developed silicon cell technology.
- Concentrating arrays entailing the use of concentrating devices such as lenses and mirrors to reduce the size of solar cell arrays required to produce usable quantities of electricity.
- Combined collectors, which represent

the use of photovoltaic arrays that produce electricity and heat.

- Development of test facilities to evaluate performance of cells, and the development of energy storage, power conditioning, and other balance-of-system components.

The System Definition and Development element provides for the development and maintenance of a photovoltaic systems analysis and engineering capability. This support activity includes:

- Developing analytic methods;
- Performing systems and tradeoff studies to guide designers, suppliers, and users of photovoltaic systems;
- Designing and developing test systems that provide an extensive data base to the photovoltaic industry; and
- Transferring photovoltaic technology to benefit industry and users.

The System Application Experiments element is the activity which is concerned with the design and installation of photovoltaic systems in a wide range of uses. Realistic applications of current technology enable prospective users to understand performance and acceptability of photovoltaic systems, as well as stimulating their commercialization. The System Application Experiments effort is concerned with:

- Demonstrating experimental applications in the 20 to 500 kW_e range;
- Gathering system performance data;
- Obtaining operational experience in Federal, industrial, commercial, residential, and utility applications;
- Prototype hardware development; and
- Encouraging investment to expend production processes and facilities.

The Standard and Performance Criteria element is oriented toward guiding the design, production, marketing, and operation of

photovoltaic conversion systems. The objective of this effort is to protect the public, industry, and commerce by:

- Developing performance criteria to provide guidelines for the design of photovoltaic systems;
- Establishing test standards and procedures to ensure that design and safety standards, building codes, and regulations are met;
- Identifying and certifying testing laboratories as part of an accreditation program to ensure consumer protection; and
- Establishing building and power plant standards and codes by providing professional and administrative consulting to organizations which develop standards and codes.

Program Activities

PROGRAM ASSESSMENT AND INTEGRATION

STATUS

During fiscal year 1978, an effort was continued to identify institutional, legal, and environmental factors affecting the photovoltaic market. This study also identified initial barriers to the use of photovoltaic systems, as well as incentives which may be provided to overcome barriers.

This effort is also addressing outstanding questions relating to technology, production, and operations in support of the overall Photovoltaic Systems Program. Among these issues are:

- Research and Advanced Development efforts that will have a major impact on the future direction of the Photovoltaic Systems Program;
- Growth of the manufacturing industry and ability to turn new technology into production capacity; and

- Applications which will provide energy alternatives in various sectors.

FUTURE EFFORT

Applications analysis for various sectors and tradeoff studies for selected applications will be completed during fiscal year 1979. The Photovoltaic Systems Program strategy will continue to be updated.

RESEARCH AND ADVANCED DEVELOPMENT PROGRAM

STATUS

During FY 78, the Research and Advanced Development Program supported work in 1) cell research in advanced materials, 2) long-range research on materials with potential for high photovoltaic conversion efficiency, 3) fundamental support research to identify basic mechanisms influencing solar cell efficiency, and 4) advanced concentrator cell concepts.

Advanced materials cell research included studies of:

- Cuprous sulfide/cadmium zinc sulfide ($\text{Cu}_2\text{S}/\text{CdZnS}$) heterojunction;
- Single and polycrystalline silicon (Si) p-n, metal-insulator - semiconductor (MIS) and conducting oxide - insulator - semiconductor (SIS) junctions;
- Amorphous silicon metal-insulator - semiconductor (MIS) junctions;
- Gallium Arsenide (GaAs) Schottky barrier p-n, metal-oxide-semiconductor (MOS), and conducting oxide-insulator-semiconductor (SIS) junctions; and
- Copper ternary/cadmium sulfide heterojunctions.

Long-range research included studies of:

- Cuprous Oxide Schottky barriers, metal-insulatory-semiconductor (MIS),

- heterojunction;
- Zinc Sulfide (Zn_3P_2) Schottky barriers;
- Copper alloys/cadmium sulfide heterojunctions;
- Zinc silicon arsenide (ZnSiAs_2) growth and characterization;
- Cadmium telluride electrodeposited p-n junctions; and
- Indium phosphide/cadmium sulphide (InP/CdS) heterojunctions.

Fundamental support research was directed to:

- Basic mechanisms limiting high-efficiency single-crystal silicon cells under one sun and concentrated sunlight;
- Laser scanning techniques for point-by-point cell characterization; and
- First principle calculations of solar cell efficiency.

Advanced concepts for concentrator solar cells included investigations of:

- Multijunction, multibandgap integrated cells; and
- Multijunction, multibandgap split spectrum cells.

INITIATIVES

The Research and Advanced Development Program issued four proposal solicitations in FY 78 to significantly expand the research effort. Program Research and Development Announcements (PRDA's) called for new studies of:

- Amorphous material
- Polycrystalline silicon
- Emerging materials
- Basic mechanisms in solar cells

Amorphous silicon work will expand in scope and include electrodeposition studies. Amorphous boron, gallium arsenide, II-IV-V compounds, and chalcogenide glasses will be studied.

New methods for growing large-grain polycrystalline thin-film silicon will be investigated. Emphasis will be placed on understanding the influence of grain boundaries on cell performance and grain boundary passivation techniques.

In the emerging materials area, the ability for thin films to reach the high potential efficiency of CdTe will receive emphasis. In addition to ongoing work in Cu_2O , ZnP, InP/CdS , ZnSiAs , BAs , CuSe , and $(\text{CH})_x$ (polyacetylene), and CdSiAs will be explored.

Fundamental studies have been initiated to identify the basic mechanisms that influence solar cell efficiency. These will include: measurements of majority and minority carrier transport across grain boundaries with controlled properties; modeling of the influence of grain boundary properties on cell current and junction characteristics; first principles theory or minority carrier recombination mechanisms under heavy doping conditions acquired in device structures; first principles solar cell modeling; new semiconductor characterization techniques; and the influence of high minority carrier injection (concentration) on minority carrier lifetime.

Technology Development

LOW-COST SOLAR ARRAY (LSA)

STATUS

The Low-Cost Solar Array Project, initiated during 1975, provided the beginning of a concerted effort aimed at the development of the technical and industrial capability to produce low-cost, long-life arrays. This project under the management of the Jet Propulsion Laboratory (JPL) has had success during this past year in meeting near-term project objectives. The LSA Project involves the in-house expertise of JPL, as well as that of numerous contractors performing under the direction and management of JPL.

The primary emphasis of the LSA Project during 1978 has been in the areas of:

- Investigating the effects of impurities in the silicon used in array fabrication;
- Developing means for producing semiconductor grade silicon at lower costs;
- Developing technology to produce large area silicon sheet at low cost;
- Improving the manufacturing processes used for array fabrication;
- Improving cell encapsulation to reduce degradation due to the environment;
- Demonstrating the capability to manufacture long-life silicon solar panels;
- Assessing current and emerging technology; and
- Introducing new manufacturing processes to industry.

Much of the work in these areas was performed through parallel, competitive efforts by industry. Solutions applicable to the overall objective are currently being evaluated.

While much of the work being conducted under the LSA Project continues into fiscal year 1979, several significant efforts were completed during fiscal year 1978. With the objective of demonstrating silicon production suitable for low-cost solar cells, methods for producing sheet silicon as well as continuous Czochralski (ingot) silicon have been pursued.

Efforts aimed at designing, fabricating, and testing high-efficiency solar cell panels were continued. The cells were evaluated, and cost estimates were developed for larger production volumes. In separate efforts assessing the current technological development of production capability and stimulating greater capability, a block of modules totaling 200 kW_e was procured. Modules delivered under these latter efforts are being used in photovoltaic system application tests.

FUTURE EFFORT

The LSA Project is yielding improved low-cost production processes for semiconductor and solar grade silicon materials. Silicon sheet technology is continuing to be developed in order to achieve a cost target of \$18 per meter² as compared to the current cost of nearly \$500 per meter². Solar cell encapsulation technology is being pursued in order to provide cells capable of a 20-year life expectancy in a terrestrial environment.

CONCENTRATOR SYSTEMS

STATUS

During fiscal year 1978, several projects relating to concentrating photovoltaic systems were continued. This work included the design, fabrication, and testing of arrays employing concentrator optics such as Fresnel lenses and reflective optics, and the development of high performance, long-life solar cells of gallium arsenide and silicon.

The major objective of the effort devoted to gallium arsenide cells was to achieve an efficiency goal of 20 percent at a specified level of concentration. Cells were manufactured which exceeded this goal.

New initiatives in fiscal year 1978 included projects aimed at:

- Fabrication of several 10 kW concentrating arrays;
- Designing advanced concentrator cells such as stacked cells from different materials; and
- Investigating novel approaches to concentration.

FUTURE EFFORT

A project aimed at developing single crystal silicon for high performance, long-life silicon solar cells for use in concentrator applications is being continued. A number of concentrator designs are being developed, which will include optimizing cell design for

large-scale production and design of the manufacturing process. Further efforts in novel cell design for high concentration use is being continued.

SYSTEMS DEFINITION AND DEVELOPMENT

STATUS

During fiscal year 1978, a major mission analysis project was continued to identify promising applications for photovoltaic total energy systems, as well as identifying incentives that will encourage the use of photovoltaic systems. An evaluation has been completed relating to the use of photovoltaic systems in single family residences.

Two parallel efforts were completed to identify the worldwide market for solar photovoltaic energy. These studies characterized the market and identified a broad range of conceivable new applications. In addition, product-year specifications were prepared for promising new market areas.

An effort was completed to enhance the participation of minority small business enterprises in the Photovoltaic Systems Program. A tradeoff analysis of the wide variety of photovoltaic systems options was continued, investigating residential applications which may become feasible by 1986. Additionally, two studies were initiated to develop innovative concepts for photovoltaic array structure and the balance-of-system components.

FUTURE EFFORT

Major initiatives under the System Definition Development effort during FY 1979 will include continuing application analyses in specific sectors, further development of methodologies related to photovoltaic generating plants, and development of simplified design methods for photovoltaic systems. A second systems and applications workshop will be conducted early in the fiscal year. Concentrator arrays will be evaluated and dense arrays of gallium arsenide cells will be tested.

SYSTEMS APPLICATION TESTS

STATUS

The Photovoltaic System Application Tests Project initiated during fiscal year 1978 was aimed at demonstrating current photovoltaic technology in a broad range of applications in order to:

- Stimulate acceptance;
- Determine system and subsystem operating characteristics; and
- Measure and diagnose cell and other component performance.

Successful early applications of photovoltaic systems have been demonstrated, including:

- Military applications
- Remote weather stations
- Highway warning signs
- Remote insect survey traps
- Forest lookouts
- Refrigerators in areas not served with electricity
- Irrigation water pumping

The System Application Tests Project provides for the development and testing of control systems for use in photovoltaics applications, and testing of photovoltaic modules. Figures 5, 6, and 7 depict a variety of successful photovoltaic systems applications.

Other efforts have included an evaluation of the use of photovoltaic systems in isolated villages, continued operation of a photovoltaic irrigation system, and the design of a residential photovoltaic application.

FUTURE EFFORT

Larger scale experiments have been selected for design during fiscal year 1978, with operation of the best design to commence in fiscal year 1979. The selection of applications and systems in future tests will be based on:

- Information to be gained;

Figure 5. Photovoltaic System Facility - Lincoln Laboratory Flight Facility,
Lexington, Massachusetts

Figure 6. The 100 kWp Photovoltaic Power System Being Constructed at the Natural Bridges National Monument, Utah (Artist's Conception)

Figure 7. Photovoltaic System Test Facility Lewis Research Center, Cleveland, Ohio (NASA Photo)

- Economics of the system compared to conventional energy sources;
- Potential for increasing market awareness;
- Degree of industry stimulation; and
- Potential contribution to non-renewable energy displacement.

STANDARDS AND PERFORMANCE CRITERIA

STATUS

The Standards and Performance Criteria effort was newly initiated in early fiscal year 1978. This effort is to address a variety of private sector factors which will facilitate the design of photovoltaic devices and systems, as well as the development of standards and performance criteria essential to the orderly assimilation of photovoltaic systems by the economy.

Criteria and standards are necessary for the design and production, marketing, and operation of solar photovoltaic conversion systems. These criteria and standards are vital for the protection of the public, generally, and the utility, industry, and commercial sectors, specifically. There are four major task areas in the program:

- Developing and publishing solar photovoltaic conversion system, subsystem, component performance, and lifetime criteria;
- Establishing standards and procedures for testing performance and lifetimes of conversion systems, subsystems, and components;
- Providing support in identifying and certifying testing laboratories qualified to conduct photovoltaic performance and lifetime tests; and
- Providing assistance in the establishment of building and power plant standards and codes.

Accelerated lifetime test standards and procedures are being developed through studies

of the relationships between environmental constituents and effects upon various materials, and through correlations with real-time and accelerated endurance tests in selected locations under a wide range of environmental conditions. The initial efforts are being carried out by several organizations and coordinated through working groups.

FUTURE EFFORT

The Standards and Performance Criteria effort will be expanded during fiscal year 1979 to assure that voluntary standards are available to guide new entries into the photovoltaic market in the early 1980's.

Major Accomplishments During Fiscal Year 1978

PROGRAM ASSESSMENT AND INTEGRATION

Major program accomplishments:

- Near-term/intermediate market studies were completed.
- Preliminary analysis of industrial applications, and second generation studies of residential, developing-country, and utility applications were initiated.
- Potential markets exist to support 1986 goals of 500 MWp at \$0.50/Wp array price.

RESEARCH AND ADVANCED DEVELOPMENT

Major program accomplishments:

- The polycrystalline thin-film $\text{Cu}_2\text{S}/\text{CdS}$ cell efficiency was increased to 9.1 percent.
- Polycrystalline thin-film p-n junction cells of Si grown by CVD on graphite reached an efficiency of 9.5 percent.
- Cells with an efficiency of 8 percent were produced from the heterojunc-

tion of SnO on cast polycrystalline Si bulk material.

- Polycrystalline thin-film p-n junction cells of GaAs grown by CVD on graphite achieved an efficiency of 6.5 percent.
- Cu ternary/CdS vapor-deposited thin-film polycrystalline cells showed an efficiency of 5.7 percent without antireflective coating.
- Single crystal, Schottky barrier grid cell efficiency of Zn_3P_2 increased from less than 1 percent to 6 percent.
- The achievability of n-and p-type ZnSiAs_2 was demonstrated in a CVD process.
- The efficiency of electrodeposited p-n junction of CdTe on indium tin oxide coated glass increased from less than 1 percent to 4 percent.
- An advance in the state-of-the-art detection of flaws in solar cells was demonstrated using laser scanning photoresponse.

TECHNOLOGY DEVELOPMENT

Major program accomplishments:

- Two polysilicon production processes which have the potential to produce less than \$10/kg material have been analytically verified and demonstrated experimentally in the laboratory. Work was initiated in the detailed design of scaled-up experimental units which will demonstrate the readiness of this technology for the development of large-scale production plants.
- Significant advancements were accomplished in the development of silicon sheet production techniques which are compatible with less than \$500/kW solar array production. Progress was realized in area growth rates, sheet quality, melt replenishment, and process control. Examples of this progress include the simultan-

eous growth of five Edge-Defined Film-Fed Growth (EFG) ribbons and the accomplishment of 15 percent efficient dendritic webs.

- During FY 78 encapsulant materials were identified for less than \$500/kW solar array modules. Also during this period, sample modules incorporating these materials were fabricated and environmental test of these modules have been initiated.
- The development of the Solar Array Manufacturing Industry Costing Standards (SAMICS) Analysis Program was refined, and employed as an evaluation tool in assessing array manufacturing processes. This modeling process is being used extensively now throughout the project and has been well received by industry personnel.
- Detailed study of the technology for a \$2/Watt flat-plate solar array production process was conducted. The results of this study indicated that this technology is presently available or under development with the LSA Project and should be ready shortly for commercial implementation.
- Technical and economic evaluation of the LSA Project status relative to the less than \$500/kW object was conducted. A "strawman" factory model was developed using specific LSA technical approaches and SAMICS modeling. The results indicated the potential to achieve an F.O.B. price between \$395 and \$490 per kilowatt depending on the solar cell efficiency and production level assumed. (\$395/kW considered a 14 percent encapsulated cell efficiency and 250 Megawatt per year production; \$490/kW considered a 12 percent encapsulated cell efficiency and 50 megawatt per year production).
- An 18 percent conversion efficiency with silicon solar cells operating at 50 suns solar intensity was achieved.
- A 28.5 percent conversion efficiency

with advanced multiple cell, spectrum splitting devices.

- Production cost analyses which indicated the near-term feasibility of \$2/Wp concentrator arrays were completed.

SYSTEMS DEFINITION AND DEVELOPMENT

Major program accomplishments included:

- Definition of the allowed Balance of System (BOS) cost for major photovoltaic power system applications;
- Prototype development of various collector designs;
- Initiation of development of low-cost structure designs;
- Hardware evaluation studies of current technology for power conditioners and storage batteries;
- Initiation of development of prototype power conditioners for PV applications; and
- Initiation of development of prototype flywheel interface units for PV residential applications.

SYSTEM APPLICATION EXPERIMENTS

Major program accomplishments included:

- Initiation of twenty-nine contracts for Phase I system design of a variety of on-site photovoltaic application experiments;
- Organization of a photovoltaic sys-

tems and applications workshop;

- Installation and operation of 26 field tests with eight organizations;
- Establishment of four Test Centers; and
- Initiation of new field tests including: a 100 kW load center (see Figure 6-National Bridge National Monument), small dispersed system for a daytime AM radio station, and a village photovoltaic power system (see Figure 8 - Indian Village -Schuchuli, Arizona).

STANDARDS AND PERFORMANCE CRITERIA

Major program accomplishments included:

- Completion of design studies, on a regional basis, of photovoltaic residential power systems; and
- Initiation of performance criteria and standards project, with SERI selected as project manager.

Photovoltaic Program Milestones

The major milestones for the Photovoltaic Systems Program are presented in Figure 9. These milestones represent the anticipated achievements in Technology Development, System Application Experiments, and the attainment of price and quantity goals.

Table 1 shows Photovoltaic Systems program funding.

Figure 8. Photovoltaic Village Power System - Papago Indian Village, Schuchuli, Arizona (NASA Photo)

Figure 9. Photovoltaic Milestones

Table 1.
Photovoltaic Systems Program Funding

Program Activity	Actual FY 1978 Obligations
Program Assessment and Integration	\$ 1,148,000
Research and Advanced Development	6,677,000
Silicon Solar Array Technology Development	31,200,000
Concentrator Technology Development	4,800,000
System Definition and Development	8,997,000
System Application Experiments	7,200,000
Standards and Performance Criteria	<div style="text-align: right;">324,000</div> <div style="text-align: right;">\$ 60,346,000</div>

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Fiscal Year 1978 — Summary Tables

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TABLE 2
PROGRAM ASSESSMENT AND INTEGRATION PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
The Aerospace Corporation	73	Photovoltaic Mission Analysis	Identify and evaluate those photovoltaic applications that are most likely to lead to significant contributions to the national energy supply, identify and evaluate strategies that will stimulate the growth of photovoltaic markets, and provide technical support to the DOE Photovoltaic Program Office.
Massachusetts Institute of Technology	74	Support for Institutional Analysis	Design research methodology to collect institutional data relevant to the small-scale daytime radio station experiment underway at the MIT Lincoln Laboratory.
Massachusetts Institute of Technology	75	Support for Market Analysis	Prepare pretesting and conducts administration coding and preliminary analysis of survey data on homeowners response to residential photovoltaic power systems.

TABLE 3
RESEARCH AND ADVANCED DEVELOPMENT PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Battelle Columbus Laboratories	79	Electrodeposited Amorphous Thin Films for Solar Cell Applications	Develop the electrodeposition process to produce amorphous silicon solar cells.
Boeing Aerospace Company	80	Cadmium Sulfide/Copper Ternary Heterojunction Cell Research	Conduct research leading to the development of a stable, polycrystalline, thin film photovoltaic solar cell of at least 4 cm ² area and 8 percent efficiency based upon the CdS/CuInSe ₂ material system.
Brown University	81	Cadmium Sulfide/Mixed Copper Ternary Semiconductor Heterojunction Solar Cell Research	Synthesize powder samples of copper ternaries, quaternary alloys, and pentanaries.
Colorado State University	82	Degradation of ITO/Silicon Solar Cells	Determine the degradation mechanisms which reduce the output power and lifetime of Indium Tin Oxide (ITO) silicon solar cells.
Colorado State University	83	Oxide Semiconductor on Silicon (OSOS) Solar Cells	Conduct studies leading to a low-cost high-energy conversion efficiency, long-life photovoltaic cell using thin films of oxide semiconductors on various forms of silicon.
University of Delaware	84	Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research	Produce thin-film polycrystalline solar cells based on the CdS/Cu ₂ S junction with energy conversion efficiencies of at least 10 percent and expected degradation rates of less than 5 percent in 20 years.

TABLE 3
RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
University of Delaware	86	Improved Semiconductors for Photovoltaic Cells - Zn_3P_2	Evaluate Zn_3P_2 as a new material for low-cost, high-efficiency, terrestrial photovoltaic cells.
Exxon Research and Engineering Company	87	Heterostructure Single-Crystal Silicon Photovoltaic Solar Cell (SnO_2)	Conduct studies leading to low-cost, high-efficiency, and long-life heterostructure SnO_2/Si solar cells.
University of Florida	88	Physical Models for Thin-Film Polycrystalline Solar Cells Based on Measured Grain-Boundary and Electronic-Parameter Properties	Develop theoretical physical models that link the power conversion efficiency, open-circuit voltage, short-circuit current, and fill factor to the dominant physical mechanisms in polycrystalline thin film solar cells.
University of Florida	89	Studies of Basic Mechanisms Influencing Solar Cell Efficiency for Terrestrial Applications	Determine and describe the basic mechanisms that control and limit solar cell power conversion efficiency, develops mathematical models that enable the inclusion of these mechanisms in the engineering design of solar cells, and explores design improvements based on the understanding gained of the basic mechanisms.
Hughes Research Laboratories	91	Photovoltaic Mechanisms in Polycrystalline Thin-Film Solar Cells	Investigate theoretically and experimentally the effect of the electronic characteristics of the grain boundary on the open circuit voltage (V_{oc}) in homojunctions and in heteroface-homojunction and heterojunction solar cells.

TABLE 3

RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Hughes Research Laboratories	92	Thin-Film Indium Phosphide (InP)/Cadmium Sulfide (CdS) Terrestrial Solar Cells	Develop the indium phosphide/cadmium sulfide (InP/CdS) heterojunction pair as an economical all-thin-film terrestrial solar cell.
Jet Propulsion Laboratory	93	High-Efficiency Thin-Film Gallium Arsenide Solar Cells	Develop a thin-film polycrystalline gallium arsenide (GaAs) solar cell with conversion efficiency greater than 15 percent and cell cost under \$0.50 per peak watt.
John Hopkins University	94	Vacuum-Deposited Polycrystalline Silicon Films for Solar Cell	Improve the structural and electrical properties of vacuum-deposited polycrystalline silicon for use in thin-film solar cells.
Lawrence Livermore Laboratory	95	Reactively Sputtered Thin-Film $\text{Cu}_2\text{S}/\text{CdS}$ Solar Cells	Develop a stable, high-efficiency thin-film $\text{CdS}/\text{Cu}_2\text{S}$ cell by reactive sputtering techniques.
Lawrence Berkeley Laboratory	96	Research on $\text{Cu}_2\text{S}/(\text{Cd},\text{Zn})\text{S}$ Photovoltaic Solar Energy Converters	Investigate the nature of $\text{Cu}_2\text{S}/(\text{Cd},\text{Zn})\text{S}$ heterostructure in order to identify those factors which ultimately limit the efficiency and stability of devices based on this structure.
Lockheed Palo Alto Research Laboratory	97	Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research	Investigate the application of the post-magnetron reactive sputtering process to the production of solar cell quality thin films of $\text{CdS}/\text{Cu}_2\text{S}$ for large-scale terrestrial photovoltaic energy conversion.

TABLE 3

RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Massachusetts Institute of Technology	98	GaAs Thin-Film Solar Cells	Develop efficient, low-cost, Gallium Arsenide (GaAs) thin-film solar cells. The program initially addressed the two principal problems involved in the fabrication process: preparation of large-grained GaAs films and formation of barriers for charge separation.
Midwest Research Institute	99	Photovoltaics Technology	Direct towards the relative commercial applications of concentrator systems and single-crystal silicon flat-plate arrays.
Mobil Tyco Solar Energy Corporation	101	Amorphous Silicon Thin-Film Heterojunction Solar Cells	Improve the conversion efficiency of solar cells formed on hydrogenated amorphous silicon.
Monosolar, Inc.	102	Electrodeposition of CdTe Solar Cells	Produce large-area, 10-percent-efficient thin-film polycrystalline solar cells by electrochemical deposition of cadmium telluride.
Motorola, Inc.	103	Thin Films of Silicon on Low-Cost Substrates	Investigate a low-cost, energy-efficient method for producing thin films of silicon suitable for the fabrication of greater-than-10-percent-efficient solar cells.
Motorola, Inc.	104	Thin-Film Polycrystalline Silicon Solar Cells	Investigate a low-cost, energy-efficient method for producing thin films of silicon suitable for the fabrication of greater-than-10-percent-efficient solar cells.

TABLE 3

RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
National Bureau of Standards	105	A Program on Solar Cell Measurement Technique Development	Develop improved solar cell measurement technology.
North Carolina State University	107	The Study of II-IV-V ₂ Chalcopyrite Semiconductors for Solar Cell Applications	Determine the properties and suitability of the II-IV-V ₂ chalcopyrite semiconductors as solar cell materials.
RCA Laboratories	108	Amorphous Silicon Solar Cells	Produce stable, low-cost (\$0.50/pW) amorphous silicon solar cells.
RCA Laboratories	109	Amorphous Thin Films for Solar Cell Applications	Develop low-cost a-Si:H solar panels with conversion efficiencies of greater than 10 percent by 1980.
RCA Laboratories	110	Thin-Film Polycrystalline Silicon Solar Cells	Characterize and correlate the electrical and structural properties of grain boundaries in polycrystalline silicon.
Rensselaer Polytechnic Institute	111	Heterostructure GaAs Solar Cells	Investigate the feasibility of fabricating Indium Tin Oxide-Gallium Arsenide (ITO/GaAs) heterojunctions using polycrystalline films of GaAs on low-cost metallic substrates.
Rensselaer Polytechnic Institute	113	Polycrystalline Thin-Film GaAs Solar Cells	Investigate the feasibility of fabricating Tin Oxide/Gallium Arsenide (SnO -GaAs) solar cells with both single and polycrystalline films of GaAs.

TABLE 3

RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Rockwell International Corporation	115	Development of High-Efficiency GaAs Solar Cells	Develop potentially low-cost, thin-film polycrystalline GaAs solar cells with 10 percent conversion efficiency, identifies the mechanisms by which grain boundaries limit cell performance, and investigates fabrication techniques and solar cell designs which minimize the adverse effects of grain boundaries.
Rockwell International Corporation	117	Thin Film of GaAs on Low-Cost Substrates	Conduct studies leading to a low-cost, high-energy, conversion-efficient, long-life photovoltaic cell using polycrystalline films of GaAs and GaAlAs.
Rockwell International Corporation	118	Thin Polycrystalline Films of Indium Phosphide on Low-Cost Substrates	Conduct fundamental studies leading to a low-cost, high-energy conversion-efficient, long-life photovoltaic cell using a polycrystalline film of Indium Phosphide (InP).
Rutgers - The State University	119	Silicon Schottky Photovoltaic Diodes for Solar Energy Conversion	Achieve a 12.5 percent AM1 efficiency on greater than 1 cm single-crystal silicon using a MIS-type structure. Study conduction mechanisms, surface states, antireflection coatings, fabrication details, solar cell models, and degradation mechanisms.

TABLE 3
RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Solarex Corporation	120	Photovoltaic Mechanisms in Polycrystalline Thin-Film Solar Cells	Study the mechanisms in thin-film polycrystalline silicon solar cells that limit the photovoltaic conversion efficiency under solar illumination conditions.
University of Southern California	121	Low-Cost Solar Cells Based on Amorphous Silicon Electrodeposited from Organic Solvents	Develop the electrodeposition process to produce amorphous silicon solar cells.
Southern Methodist University	122	Silicon Thin Films on Metallurgical Silicon Substrates	Investigate silicon films on metallurgical silicon substrates in order to produce thin film solar cells with an AM1 efficiency of 10 percent by 1979.
Southern Methodist University	123	Thin Films of Gallium Arsenide on Low-Cost Substrates	Investigate gallium arsenide films on tungsten/graphite and other low-cost substrates in order to produce thin-film solar cells with an AM1 efficiency of 6 percent or higher.
Sperry Univac	124	Cadmium Sulfide/Copper Ternary Heterojunction Cell Research	Develop a cadmium sulfide/copper ternary heteromass 1 conversion efficiency of no less than 8 percent (as measured between 20 C and 30 C over cell areas of at least 4cm), with a maximum electrical output degradation of 5 percent over 20 years.

TABLE 3
RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Spire Corporation	125	Development of Silicon Recrystallization and Thin-Film Solar Cell Processes	Investigate the recrystallization technique and other special processing techniques for the fabrication of thin film solar cells with a conversion efficiency of at least 10 percent.
Syracuse University	126	Heterojunction Solar Cells	Study the principles of operation of heterojunction solar cells (HJSC's) and evaluated the practicality of their use for low-cost, large scale photovoltaic energy conversion. Particular emphasis was placed on the investigation of potential degradation mechanisms.
University of Washington	127	Investigation of Low-Cost Solar Cells Based on Cu_2O	Investigate the photovoltaic properties of solar cells based on Cu_2O , particularly with respect to their potential for low-cost photovoltaic power conversion.
Wayne State University	128	Cuprous Oxide Photovoltaic Cells	Develop methods for the production of low-cost photovoltaic cells based on cuprous oxide (Cu_2O).
Westinghouse Electric	130	Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research	Conduct research for developing cadmium sulfide/copper sulfide thin-film solar cells capable of 10 percent AM1 cell conversion efficiency with less than 5 percent degradation in performance over a useful life of 20 years.

TABLE 3
RESEARCH AND ADVANCED DEVELOPMENT PROJECTS (concluded)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Westinghouse Electric Corporation	131	Heterostructure Single-Crystal Silicon Photovoltaic Solar Cells; Type B: Metal Heterojunction Silicon Devices (MHS Silicon Cells)	Fabricate, test, evaluate, and model photovoltaic cells of the Al-SiO ₂ -Si variety to assess their technical and commercial practicability for power generation.

TABLE 4
TECHNOLOGY DEVELOPMENT
LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Aerochem, Inc.	137	Development of Model and Computer Code for Si Reactions	Develop model and computer code for Si reactions.
Aerochem, Inc.	138	Silicon Halide-Alkali Metal Flames as a Source of Solar Grade Silicon	Develop process for producing Si using silicon halide-alkali metal flames.
Aerochem, Inc.	139	Synthesis of Silane and Silicon	Determine the practicality of using a nonequilibrium plasma jet for the low-cost, high-volume production of silane and silicon.
35 Aerospace Corporation	140	Composition Measurements by Analytical Photon Catalysis	Conduct an investigation to develop the use of Analytical Photon Catalysis and assess the applicability of this technique for making composition analysis of silicon samples.
Arco Solar, Inc.	141	35 kW - Block III	Design and develop a solar array module with high reliability, while incorporating design features which will result in a lower fabrication cost than conventional modules.
Theodore Barry and Associates	142	Lifetime Cost and Performance Modeling Effort Support	Review and critique the methodology to define the overall structure of the Lifetime Cost and Performance (LCP) model and identify inconsistencies.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Theodore Barry and Associates	143	Phase II Industrial Engineering Study	Provide additional standard data for use in the Solar Array Manufacturing Industry Costing Standards (SAMICS) to extend the hypothetical factories to include warehousing, distribution, sales, and marketing functions and to vary the factory operating schedules.
Theodore Barry and Associates	144	Solar Array Manufacturing Industry Costing Standards	Provide additional validation of the Solar Array Manufacturing Industry Simulation, 3rd (SAMICS III) computer program.
Battelle Memorial Institute	145	Die and Container Materials	Conduct a study program to develop methods for processing and fabricating selected refractory materials into a form which is resistant to the corrosive action of molten silicon and which is amenable to the production of ribbon-forming dies and containers for molten silicon.
Battelle Memorial Institute	146	Environmental Definition, Materials Evaluation, and Testing	Create six interrelated studies.
Battelle Memorial Institute	148	Semiconductor Grade Si Process	Establish a chemical process for producing semiconductor grade silicon at a rate and price commensurate with the goals of the LSA Project.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Bechtel Corporation	150	Array Life-Cycle Analysis	Provide detailed costing relationships in/support of the life-cycle cost modeling effort undertaken by the Array Life-Cycle Analysis Task within the Project Analysis and Integration Area of LSA.
Bechtel Corporation	151	Requirements for Solar Array	Perform studies to determine the optimum photovoltaic module size, configuration, and construction by determining the lowest cost module-panel structure-foundation system.
The Boeing Company	152	Feasibility Study of Solar Dome Encapsulation of Photovoltaic Arrays	Perform studies to evaluate the use of an air-supported enclosure for encapsulation of photovoltaic solar arrays. Determine and assess the potential technical and economic benefits obtained when solar photovoltaic arrays are protected by the air-supported structures.
Burt, Hill, Kosar, Rittelmann Associates	153	Residential Photovoltaic Module Requirements Study	Provide engineering services and other necessary support to derive a preliminary residential photovoltaic module specification together with supporting rationale.
University of California, Los Angeles	154	Development and Application of X-Ray Defraction Technique	Develop methods of characterizing large-area silicon crystals supplied by JPL with X-ray diffraction techniques.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
University of California, Los Angeles	155	Silicon Solar Cell Fabrication Technology	Provide device fabrication services in support of silicon sheet evaluation.
Case Western Reserve University	156	System Studies Basic Aging and Diffusion	Determine the effects of progressive degradation caused by environmental stresses on the permeability of en- capsulants.
Clemson University	157	Solar Cell Reliability Test	Provide for investigations of factors involved in the reliability of terres- trial solar cells and develop a specifi- cation for accelerated stress testing of solar cells.
Coors Procelain Co.	158	Low-Cost Silicon Array Container Material.	Develop and test low-cost mullite for potential application as a substrate and crucible material.
Cornell University	159	Characterization of Structural, Electrical, and Chemical Properties of Silicon	Provide the basic research efforts towards correlating the structural, electrical, and chemical properties of silicon sheet material.
Crystal Systems, Inc.	160	HEM Slicing Process	Develop methods (feasibility) to pro- duce large areas of silicon sheet ma- terial, by the heat exchanger ingot casting/slicing process, suitable for use as cost-effective solar cells.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
LOW-COST SOLAR ARRAY (LSA) PROJECTS

	<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
	Dow Corning Corporation	161	Encapsulation System for Silicon Solar Arrays	Develop and characterize improved silicon and silicon-based materials for encapsulation systems suitable for low-cost solar cell modules up to 48 x 48 inches in size for service in terrestrial environments for a minimum of 20 years.
	Dow Corning Corporation	162	Solar Cell Grade Si Process, ARC Furnace	Determine the feasibility of an arc-furnace process for the production of silicon (Si).
39	Eagle-Picher Industries, Inc.	164	Die and Container Materials	Conduct a study program to develop methods for processing and fabricating selected refractory materials into a form which is resistant to the corrosive action of molten silicon and which is amenable to the production of ribbon-forming dies and containers for molten silicon.
	Endurex Corporation	165	Solar Cell Module Ion-Plating	Conduct a detailed investigation and study into the feasibility of encapsulating silicon solar cells, electrical interconnects, silicon solar cell arrays by ion-plating onto the surfaces thereof, transparent barrier coatings of metal oxides, and rare-earth element oxides.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
 LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
General Electric Company	166	Development and Testing of Shingle-Type Solar Cell Modules	Design, develop, fabricate, and test silicon solar cell modules which are suitable for use in place of roofing shingles on residential or commercial buildings.
General Electric Company	167	Floating Substrate Sheet Growth Process	Explore basic principles and determine parameters for the floating substrate process.
Gnostic Concepts, Inc.	168	Industrialization Study	Perform a study to develop a detailed understanding of the decision process by which industrial concerns evaluate investment ventures in photovoltaics manufacture.
Honeywell, Inc.	169	Novel Growth-Dip Coating	Investigate the economic feasibility of producing solar cell quality sheet silicon by coating one surface of carbonized ceramic substrates with a thin film of silicon from melt.
Kayex Corporation	170	Development of Advanced Methods for Continuous CZO Si Growth	Develop a method of continuous Czochralski growth process capable of producing silicon sheet suitable for fabricating solar cells that would meet the technical goals of the Low-Cost Solar Array Project.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Kinetic Coatings, Inc.	171	Phase II of the Array Automated Assembly Task	Investigate the use of ion implantation, ion beam sputtering, and electron beam deposition techniques for a simplified process.
Lamar University	172	Process Feasibility Study	Conduct a series of economic analyses of Si process developments.
Lockheed Missiles and Space Company, Inc.	173	Phase II of the Array Automated Assembly Task	Develop and verify processes for making solar cells and modules from Czochralski single-crystal silicon.
Lockheed Missiles and Space Company, Inc.	174	Spraylon Fluorocarbon Encapsulation for Silicon Solar Cell Arrays	Design, develop, and verify the application of a low-cost fluorocarbon encapsulant system called Spraylon to terrestrial solar modules.
Materials Research, Inc.	175	Quantative Analysis of Defects in Silicon	Provide for the development of methods characterizing silicon crystals according to grain size, dislocation density, twin boundary spacing, twin boundary density, and density of impurity precipitates.
Materials Research, Inc.	176	X-ray Analysis of Silicon Wafers	Study nondestructively the crystallographic structure defects in the silicon wafers deliberately doped with impurities.
MB Associates	177	Array Automated Assembly Task	Develop a manufacturing process sequence which when implemented on a manufacturing line will produce silicon solar modules at a cost of \$.50/W by 1986.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
 LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Mobil Tyco Solar Energy Corp.	179	Ribbons Growth - EFG	Develop methods of producing large areas of silicon ribbon by edge-defined, film-fed growth (EFG) technique.
Mobil Tyco Solar Energy Corp.	180	Six Solar Modules	Develop and design solar array modules capable of performing within the environmental limits.
Motorola, Inc.	181	50 kW - Block III	Provide for manufacture, test, and delivery of a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 50 kilowatts.
Motorola, Inc.	182	Laser-Zone Growth in a Ribbon to Ribbon Process	Demonstrate the feasibility of producing large-area silicon sheet by laser-zone growth using a ribbon-to-ribbon (RTR) process.
Motorola, Inc.	183	Metallization of Large Silicon Wafers	Develop and verify processes for a nickel-palladium metallization system.
Motorola, Inc.	184	Phase II Automated Array	Design, develop, and verify the performance of solar array production process steps which represent a significant technical extrapolation from state-of-the-art production approaches.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Motorola, Inc.	186	Semiconductor Grade Si Process	Determine the feasibility of a cyclic chemical process for producing silicon (Si) from a polymeric silicon difluoride (SiF ₂) intermediate.
Motorola, Inc.	187	Solar Cell Modules with Parallel Oriented Interconnections	Provide for evaluation a total of 24 R&D solar panels which are designed to meet JPL Specification 5-342-1B, "Silicon Solar Cell Module Performance, Environmental Test and Inspection Requirements."
Motorola, Inc.	188	Technology Assessment	Perform an assessment of the improvements in current technology that may be needed to develop, within a period of no more than 10 years, an industrial capability for low-cost, mass production of solar arrays and modules.
National Bureau of Standards	190	Neutron Activation Analysis	Develop a procedure for measurements of compositions by Neutron Activation Analysis and Spark Source Mass Spectrometry.
Northrop Corporation	192	Lifetime Measurement Analysis	Perform measurements of (1) minority-carrier recombination lifetime in bulk silicon and (2) diffusion length in solar cells fabricated from the same material in order to assess the sensitivity of these parameters to the presence of impurities.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Optical Coating Laboratory, Inc.	193	High-Efficiency Long-Life Solar Panels	Design, fabricate, and deliver high-efficiency, long-life terrestrial silicon solar panels utilizing high-efficiency solar cells and increased packing density.
Optical Coating Laboratory, Inc.	194	Ion-Implanted Solar Cells	Provide the determination of the effects of certain ion-implanted impurities on solar cell performance.
Optical Coating Laboratory, Inc.	195	Sawing Techniques	Evaluate existing technology utilized in the sawing of 7.8 cm and 10.2 cm diameter silicon ingots, with a major emphasis on using internal diameter (ID) blade saws.
Optical Coating Laboratory, Inc.	196	Silicon Solar Cell Process Development	Evaluate the solar cell and the potential of unconventional silicon sheets.
University of Pennsylvania	197	Analysis and Evaluation of Processes and Equipment	Perform expert analyses and critical evaluation of processes and equipment, proposed or designed, for the high-volume production of Low-Cost Solar Array (LSA) Modules.
RCA Corporation	199	Development and Evaluation of Die Materials for Producing Silicon Ribbons by Inverted Ribbon Growth	Develop chemically vapor-deposited die materials capable of producing good quality silicon ribbon by the Inverted Ribbon Growth (IRG) process.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
RCA Corporation	200	Epitaxial Silicon Growth for Solar Cells	Develop and demonstrate the feasibility of an epitaxial silicon growth process on low-cost silicon substrates to produce epitaxial silicon material suitable for solar cells.
RCA Corporation	201	Phase II of the Automated Array Assembly Task of the LSA Project	Perform an assessment of the improvements in current technology that may be needed to develop, within a period of no more than 10 years, an industrial capability for low-cost, mass production of solar arrays and modules.
RCA Corporation	203	Phase II of the Automated Assembly Task 4	Develop and verify processes for making solar cells and modules from Czochralski single-crystal silicon.
Rockwell International Corp.	204	Materials Interface Problem Study	Study by physical/chemical methods the mechanisms in silicon solar cell encapsulant systems induced by the singular and combined effects of moisture, temperature, and UV radiation.
Rockwell International Corp.	205	Test Methods and Aging Mechanisms	Develop a methodology for predicting the performance of solar cells in encapsulants for periods of up to 20 years.
C. T. Sah Associates	206	Study Effect of Impurities in Silicon Materials	Study the effects of impurities on Si materials and on performance of solar cells.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
J. C. Schumacher Co.	207	High-Velocity Continuous Flow Reactor	Determine the technical feasibility of a high-velocity, gaseous-reaction process for the hydrogen reduction of bromosilanes utilizing a continuous-flow reactor in which silicon (Si) particles are continuously introduced.
Sensor Technology, Inc.	208	5 kW - Block III	Manufacture, test, and deliver a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 5 kilowatts.
Sensor Technology, Inc.	209	40 kW - Block III	Provide for the manufacture, test, and delivery of a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 40 kilowatts.
Sensor Technology, Inc.	210	High-Efficiency Panels	Develop and verify volume processes for making the solar modules from single-crystal Czochralski silicon.
Sensor Technology, Inc.	211	Phase II of the Array Automated Assembly Task	Design, develop and verify the performance of solar array production process steps which represent a significant technical extrapolation from state-of-the-art production approaches.
Siltec Corporation	212	Development of Advanced Methods for Continuous CZO Growth	Develop methods of demonstrating continuous Czochralski growth process capable of producing silicon suitable for use as low-cost solar cells.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Solar Power Corporation	213	50 kW - Block III	Provide solar cell modules equating to a total integrated power capacity of 50 kW.
Solarex Corporation	214	Array Automated Assembly Task for LSA Project	Develop and specify a solar cell module process sequence which, when automated, would have the potential of mass producing silicon solar array modules encapsulated for protection against Earth's environment.
Solarex Corporation	216	5 kW - Block III	Provide for the manufacture, test, and delivery of a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 5 kilowatts.
Solarex Corporation	217	High-Density Silicon Solar Panels	Develop and verify processes for making solar modules utilizing 5 cm x 5 cm square cells.
Solarex Corporation	218	Solar Breeding Feasibility	Explores the feasibility of manufacturing photovoltaic solar array modules with electrical energy generated from photovoltaic devices.
Solarex Corporation	219	30 kW - Block III	Provide for the manufacture, test, and delivery of silicon solar cell modules to provide a total integrated power capacity of 30 kilowatts.

TABLE 4

TECHNOLOGY DEVELOPMENT (cont.)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Solarex Corporation	220	Water Thickness Evaluation	Provide expert analysis and critical evaluation of the technical feasibility and effective cost of various wafer thickness for the manufacture of solar cells.
Spectrolab, Inc.	221	Automated Array Assembly Task	Develop and specify a solar cell module process sequence which emphasizes thick-film metallization and wrap around contacts over thick-film insulation on solar cells.
Spectrolab, Inc.	223	Solar Modules 40 kW - Block II	Assess the current state-of-the-art for module production, price, and design features; stimulate production capacity for solar cell modules; and provide modules for use in the photovoltaic test and application projects.
Spire Corporation	224	Development and Test Encapsulation Materials for LSA	Design, develop, and test equipment and processes to determine the feasibility of protecting solar cells by integral glass encapsulation.
Spire Corporation	225	Development of Pulsed Process for the Manufacture of Solar Cells	Develop ion implantation and associated pulsed-energy processes for low-cost manufacturing of solar cells.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
 LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Springborn Laboratories	227	Encapsulation - Test Methods and Materials Properties Evaluation	Carry out the necessary studies, analyses, testing, formulation development, and modification of materials as necessary in order to recommend materials, processes, and system design features for low-cost (approximately 23¢/ft ²) automated encapsulation of solar cell modules.
Stanford Research Institute	228	Duplex Vapor Electrochemical Method for Silicon Production	Develop process for producing SiF by reducing SiF ₄ with Na and using SiF ₄ /SiF ₂ transport reaction for purification.
Texas Instruments, Inc.	229	Array Automated Assembly Task	Consider various "forms of silicon" suitable for automatic processing of low-cost solar cells. Perform (1) trade-off studies relating projected costs, electrical performance, and life expectancy; (2) studies of interconnect technology for electrically joining solar cells in series and parallel; and (3) studies of applicability of present state-of-art manufacturing technology to a fully automated manufacturing facility.
Texas Instruments, Inc.	230	Closed-Cycle Reactor Process for Producing Silicon	Provide the technical feasibility of a closed-cycle process for producing Si suitable for fabricating solar cells.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Texas Instruments, Inc.	231	Development of Advanced Methods for Continuous CZO Growth of Si	Demonstrate the Czochralski growth of 100 kg silicon single-crystal ingot of 10 cm diameter utilizing one common crucible by continuous melt replenishment.
Texas Instruments, Inc.	232	Development of Automated Array Processes	Design, develop, and verify the performance of solar array production process steps which represent a significant technical extrapolation from state-of-the-art production processes.
Texas Instruments, Inc.	233	Development of Tandem-Junction Cell	Provide a modified Program Plan and a modified Process Development Plan to further develop the tandem-junction cell to produce 2 cm x 2 cm cells with an AM1 efficiency of 16 to 17 percent.
Tylan Corporation	234	Vitregraph Coating on Mullite	Develop a series of Vitregraph coatings on special substrates and evaluate the nature and geometry of these coatings.
Union Carbide Corporation	235	Semiconductor Grade Si Process - Silane/Silicon	Develop a process for producing Si by incorporating a process for producing silane (SiH ₄) and then a process for converting SiH ₄ into Si.

TABLE 4
TECHNOLOGY DEVELOPMENT (cont.)
LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Varian Associates, Inc.	236	Development of Advanced Methods for CZO Growth	Develop a method of continuous Czochralski growth capable of producing silicon sheet suitable for fabricating solar cells that would meet the technical and cost goals of the Low-Cost Solar Array Project.
Varian Associates, Inc.	237	Slicing of Si Ingots for LASS of LSA	Develop methods to slice silicon into sheet material suitable for use as solar cells. The program is directed towards preparation of lowest silicon sheet by ingot slicing.
Westinghouse Electric Corporation	238	High-Capacity Arc Heater Process	Establish the practicality of an arc heater process incorporating the reduction of silicon tetrachloride for the low-cost, high-volume production of solar cell grade silicon.
Westinghouse Electric Corporation	239	Phase II Automated Array Assembly Task	Develop and verify processes for making solar cells from dendritic web silicon ribbon.
Westinghouse Electric Corporation	240	Solar Cell Grade Si Definition	Investigate the effects of impurities, various processes, and impurity-process interactions on the performance of terrestrial silicon solar cells in order to determine the purity requirement for a solar cell grade silicon.

TABLE 4

TECHNOLOGY DEVELOPMENT (concluded)

LOW-COST SOLAR ARRAY (LSA) PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Westinghouse Electric Corporation	241	Web Dendritic Process Development	Develop methods of producing low-cost silicon sheet suitable for cost-effective solar cells by the Web Dendritic process.
Xerox Corporation	242	Center-Hole-Punched Solar Module Development Effort.	Design and fabricate a solar module that demonstrates a potential reduction in panel and automated assembly costs by incorporating a mechanical interconnect scheme to eliminate the need for welding or soldering interconnects to solar cells.

TABLE 5
TECHNOLOGY DEVELOPMENT
CONCENTRATOR SYSTEMS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
AAI Corporation	245	10 Kilowatt Central Receiver Array	Design a 10 kilowatt central receiver photovoltaic array.
Acurex Corporation	246	Parabolic Trough PV Concentrator Commercialization	Develop a design for a photovoltaic/thermal receiver suitable for operation in the standard Acurex parabolic trough module.
Acurex Corporation	247	Sealed-Glass Concentrator Module Development	Develop a photovoltaic concentrator module which essentially utilizes technology similarly employed in the manufacture of sealed-beam auto and aircraft headlights.
Arco Solar, Inc.	248	Design and Fabrication of Prototype Combined PV/Thermal Non-Tracking Collectors	Obtain combined photovoltaic/thermal flat-panel collectors suitable for roof-mounted operation for purposes of test and evaluation.
University of Arizona	249	Sectored Reflective Dish PV Module Development	Develop a module which is similar to the Cassegrain module being proposed for incorporation in the Arizona Public Service photovoltaic concentrator applications experiment at the Phoenix airport.
California Institute of Technology	250	Fluorescent Concentrator Study	Develop a basic understanding of the luminescent solar concentrator concept.
General Electric Company	251	Concentrating Array Production Process Design	Design concentrator arrays for large-scale production and manufacturing processes to be used for fabrication.

TABLE 5
TECHNOLOGY DEVELOPMENT (cont.)
CONCENTRATOR SYSTEMS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Honeywell Corporation	252	10 Kilowatt Actively Cooled PV Concentrator System	Design a 10 kilowatt actively cooled photovoltaic concentrator array.
Martin Marietta Corporation	253	10 kW Fresnel Lens PV Array	Fabricate a 10 kilowatt concentrator array. The photovoltaic modules use Fresnel lenses to concentrate energy onto silicon solar cells.
Motorola, Inc.	254	Hybrid Solar Tracker	Develop a hybrid solar tracking unit that will be adaptable to a large variety of concentrating arrays.
Motorola, Inc.	255	Silicon Concentrator Solar Cell Manufacturing Development	Develop manufacturing processes for fabricating high-performance, long-life single-crystal silicon solar cells for operation in solar concentrator systems.
Motorola, Inc.	256	Two-Axis Tracking Array	Design and construct a two-axis tracking platform suitable for mounting various concentrator modules.
North Carolina Agriculture and Technical State University	257	Solar Cell Evaluation	Carry out performance characterization measurements on concentrator solar cells and evaluate the long-term stability and reliability of concentrator cells.
Owens-Illinois	258	Luminescent Photovoltaic Concentrator Development	Assess the feasibility of using luminescent dyes doped in suitable plastic or acrylic substrates to absorb solar radiation.

TABLE 5
TECHNOLOGY DEVELOPMENT (cont.)
CONCENTRATOR SYSTEMS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
RCA Corporation	259	Laminated Fresnel Lens Development	Develop Fresnel lenses which are formed by molding optical grade epoxies into facets directly on a glass substrate.
Research Triangle Institute	260	Novel Concentrator Photovoltaic Converter System Development	Explore novel solar cell or photovoltaic converter system concepts which have the potential of conversion efficiencies greater than 25 percent.
Rockwell International	261	Gallium Arsenide PV Dense Array for Concentrator Applications	Design and fabricate a 20 kWe GaAs cell dense array with integral heat sinking to be tested on the central tower receiver facility called the Solar Thermal Test Facility (STTF) at Sandia Laboratories.
Selectro-Thermo, Inc.	262	STI PV Array	Purchase one Selectro-Thermo Model A160-6 160 ft ² concentrating photovoltaic array with battery and two 16 ft ² modules for the A160-6 array.
Solarex Corporation	263	Solar Cell Manufacture	Develop manufacturing procedures for mass producing silicon solar cells of high power conversion efficiency.
Spectrolab, Inc.	264	Design and Fabrication of Prototype Combined Photovoltaic Thermal Non-Tracking Collectors	Obtain combined photovoltaic/thermal flat-panel collectors suitable for roof-mounted operation for purposes of test and evaluation.

TABLE 5

TECHNOLOGY DEVELOPMENT (cont.)

CONCENTRATOR SYSTEMS

Organization	Page	Title	Projected Contribution
Spectrolab, Inc.	265	Hybrid Photovoltaic/Thermal Electric Analysis	Determine whether the combining of photovoltaic and thermodynamic conversion techniques in a single solar-electric system is more cost effective than solar photovoltaic or solar thermal electric schemes individually.
Spectrolab, Inc.	236	Polar-Mounted PV Parabolic Trough Commercialization	Design a one-half parabola module which includes a compound elliptical concentrating secondary.
Spectrolab, Inc.	267	Ten kW Photovoltaic Concentrator	Fabricate a 10 kilowatt array which utilizes an off-axis half-parabolic trough.
Sun Trac Corporation	268	Sphere Enclosed CPC Photovoltaic Concentrator Commercialization	Develop a new array design, fabricate a prototype, and prepare for limited production of these arrays for commercial sales.
Swedlow, Inc.	269	2000:1 Fresnel Lens	Develop a Fresnel lens capable of producing concentration ratios of 125, 250, 500, 750, 1,000, 1,250, 1,500, 1,750, and 2,000 suns over a target area of 1 inch in diameter.
Swedlow, Inc.	270	Fresnel Lens Analyzer Design Fabrication	Design a Fresnel lens analyzer to rapidly test and quantify the characteristics of Fresnel lenses.

TABLE 5

TECHNOLOGY DEVELOPMENT (concluded)
CONCENTRATOR SYSTEMS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Varian Associates	271	Novel Concentrator Photovoltaic Converter System	Explore novel solar cell or photovoltaic converter system concepts which have the potential of conversion efficiencies greater than 25 percent.

TABLE 6
SYSTEM DEFINITION AND DEVELOPMENT PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Abacus Controls, Inc.	275	Ten kVa Power Conditioning Unit	Modify the 10 kVa transistorized inverter developed under NASA contract to make it more reliable and versatile.
Arizona State University	276	PV Subsystem Model and Load Study	Investigate simplifications in the modeling of photovoltaic subsystem components and assess design sensitivity to system electrical load variations.
Arizona State University	277	Solar Photovoltaic Test and Evaluation Program	Conduct cell technology evaluation, array testing, thermal analysis and testing, experimental program consulting, and proposal review.
BDM Corporation	278	Analysis of Design Tradeoffs and Transient Effects in Large Photovoltaic Arrays	Develop a computer code to simulate large photovoltaic arrays. The code will be exercised to investigate design tradeoffs and transient effects in large photovoltaic arrays.
BDM Corporation	279	Photovoltaic Applications Definition and Photovoltaic System Definition Study in the Agriculture Sector	Identify promising electrical loads in the agricultural sector that can be supplied with solar photovoltaic energy, and provide conceptual designs of photovoltaic power systems for chosen applications.

TABLE 6
SYSTEM DEFINITION AND DEVELOPMENT PROJECTS (cont.)

	<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
	BDM Corporation	280	PV Programming Support Services	Provide programming support for in-house photovoltaic analysis, i.e., code modifications, program operations, documentation on code changes, code checkouts, comparison of results, and maintenance of program files.
	Bechtel Corporation	281	Battery Storage Performance Requirements for Terrestrial Solar Photovoltaic Power Systems	Assess the performance requirements for near- and mid-term batteries for application to solar photovoltaic and solar photovoltaic power systems.
59	Bechtel Corporation	282	Requirement Definition and Preliminary Design of a PV Central Power Station Experimental Test Facility	Provide the physical and electrical design and site specifications for a 1 to 2 MWe photovoltaic central power station.
	General Electric, Co.	283	Requirement Definition and Preliminary Design of a PV Central Power Station Experimental Test Facility	Provide the physical and electrical design and site specifications for a 1 to 2 MWe photovoltaic central power station.
	Massachusetts Institute of Technology Lincoln Laboratory	284	Solar Photovoltaic Field Tests and Applications Project	Establish technical feasibility of photovoltaic (PV) power systems in a variety of applications.
	Mission Research Corporation	285	Analysis of the Effects of Lightning on Solar Photovoltaic Arrays	Determine the responses of the complete array system and its subsystems to the lightning environment and; determine lightning protection schemes and hardness design criteria for the complete system.

TABLE 6

SYSTEM DEFINITION AND DEVELOPMENT PROJECTS (concluded)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
University of Nebraska	286	Solar-Cell-Powered Irrigation Pumping Plant and Other Alternate Uses	Operate and maintain the 25 kW solar-cell-powered system installed by DOE at the University of Nebraska experimental energy farm located at Mead, Nebraska.
Sandia Laboratories	287	Photovoltaic Projects Division	Plan, organize, and manage a program to analyze and provide conceptual, preliminary and detailed designs of photovoltaic electric power systems.
Westinghouse Corporation	288	Design and Construction of a 40 to 50 kVa Power Conditioning Unit for PV Power Systems	Design, construct, bench test, and deliver one production prototype 40 to 50 kVa power conditioning unit for incorporation in a photovoltaic power system.
Woodward-Clyde Consultants	289	Decision Analysis Methodology for PRDA-35	Provide a decision analysis methodology, including the appropriate attributes, weightings, and tradeoff factors, to be used to evaluate and rank order proposals for the implementation of photovoltaic concentrator experiments.
Woodward-Clyde Consultants	290	Decision Analysis Methodology for PRDA-38	Review the list of attributes and scales developed by Sandia for the PRDA-35 selection process and makes appropriate changes.

TABLE 7

SYSTEM APPLICATION EXPERIMENTS PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Abacus Controls, Inc.	293	Production Prototype Inverter for Photovoltaic Applications	Design, test, and fabricate a 10 KVA self-commutated inverter to be used in photovoltaic power.
Acurex Corporation	294	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Arizona Public Service Co.	295	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Arizona State University	296	Study of the Social and Economic Impact of Photovoltaic Power on the Papago Indian Village of Schuchuli, Arizona	Determine the significant social and economic effects of introducing a solar cell power system into the Indian village of Schuchuli, Arizona.
Battelle Corporation	297	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
BDM Corporation	298	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Booz-Allen-Hamilton	299	Schuchuli Operational Manual	Provide services, labor, and materials to write an operations manual for a photovoltaic power system to be installed in the Papago Indian village of Schuchuli (Gunsight), Arizona.

TABLE 7
SYSTEM APPLICATION EXPERIMENTS PROJECTS (cont.)

	<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
	Carr Liggett Advertising, Inc.	300	Press Releases, Technical Article and Dedication Ceremonies	Supply the necessary materials and manpower for press releases, technical articles, and dedication ceremonies concerning experimental solar cell powered systems at: (1) a forest lookout tower in Lassen National Forest, CA; (2) the Papago Village Power Project at Schuchuli, AZ; and (3) an air pollution monitor in Liberty Park, NJ.
29	Department of Defense, US Army Mobility Equipment Research and Development Command	301	Military Applications of Photovoltaic Systems	Construct six solar cell power systems for candidate military applications.
	Delta Electronic Control Corporation	302	60 Kilowatt Solid State Inverter/Solar Cell Array	Demonstrate that a dc-ac photovoltaic energy conversion system without energy storage can effectively augment a remote military power network.
	Desert Sunshine Exposure Tests, Inc.	303	Exposure Tests	Rent several DSET standard solar test machines for solar cell module material exposure to concentrated sunlight; modify three machines for special test purposes.
	DIKU, Inc.	304	Solar Cell Module Inspection and Testing	Receive, process, and inventory solar cell modules for Lewis Research Center applications from the JPL procurements.

TABLE 7

SYSTEM APPLICATION EXPERIMENTS PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
E-Systems, Inc.	305	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Energy Analysis, Inc.	306	Low-Power Terrestrial Photovoltaic System Design Information Reference	Prepare a reference handbook, for use by applications engineers using hand-held computers, containing information to configure and design terrestrial PV systems under 10 kWp in size.
General Electric Company	307	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
InterTech/Solar Corporation	308	Array Structure Design Reference for Low-Power Photovoltaic Applications (up to 10 kW)	Prepare a reference handbook, for use by applications engineers using hand-held computers, detailing module, panel and array structural requirements for PV systems under 10 kWp in size.
InterTech/Solar Corporation	309	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Kaman Sciences Corporation	310	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
City of Los Angeles Department of Water and Power	311	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.

TABLE 7

SYSTEM APPLICATION EXPERIMENTS PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Martin Marietta Corporation	312	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Motorola, Inc.	313	Market Definition Studies for Photovoltaic Village Power Applications	Identify the opportunities in the U.S. and its possessions for photovoltaics in the village power application market.
NASA, Lewis Research Center	314	Photovoltaic Tests and Applications Project	(1) Stimulate near-term markets for cost effective applications of photovoltaic systems; (2) determine operating characteristics for a variety of solar cell systems and subsystems; (3) devise and implement the methodology, techniques, and equipment to make accurate and reproducible measurements of solar cell and array performance, and diagnostic measurements on solar cells, modules and arrays; and (4) determine the endurance of solar cell modules, component parts, and their materials under environmental conditions of their intended use.
National Bureau of Standards	315	Investigation of Techniques for Measuring the Absolute Spectral Response of Solar Cells	Characterize solar cells by their absolute spectral response (milliampere short-circuit current output per milliwatts/cm irradiance input for small wavelength intervals over the wavelength range from 0.3 to 1.2 m).

TABLE 7
SYSTEM APPLICATION EXPERIMENTS PROJECTS (cont.)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Naval Weapons Support Center	316	Tropical Testing	Perform accelerated endurance tests on Block II solar cell modules under simulated environments.
Commonwealth of Puerto Rico, Office of the Governor	317	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Research Triangle Institute	318	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Solarex Corporation	319	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Spectrolab, Inc.	320	Pulsed Solar Simulator	Build a pulsed solar simulator complete with data acquisition system to be used in calibrating and testing solar cells and panels.
Sun Trac Corp.	321	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Technical Marketing Associates, Inc.	322	Market Definition Study for Highway Applications	Identify major opportunities for photovoltaics in the highway application market.
Texas Technical University	323	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.

TABLE 7
SYSTEM APPLICATION EXPERIMENTS PROJECTS (concluded)

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Tracor Northern, Inc.	324	Optical Multichannel Analyzer System	Provide a custom-built optical multi-channel analyzer system. The system is needed to study total and diffuse sky irradiance of solar cells as well as their response to other light sources such as solar simulators.
Varian Associates, Inc.	325	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.
Westinghouse Electric Corporation	326	Photovoltaic Concentrator Application Experiment	Gain practical experience in operating PV concentrator on-site equipment.

TABLE 8
STANDARDS AND PERFORMANCE CRITERIA PROJECTS

<i>Organization</i>	<i>Page</i>	<i>Title</i>	<i>Projected Contribution</i>
Massachusetts Institute of Technology Lincoln Laboratory	329	Photovoltaics Interim Performance Criteria and Test Methodology	Develop interim performance criteria and test methodology for photovoltaics.
National Bureau of Standards	330	Photovoltaic Interim Performance Criteria and Test Methodology	Develop interim performance criteria and test methodology for photovoltaics.
Solar Energy Research Institute	331	Performance Criteria and Test Methodology for Photovoltaics	Develop performance criteria and test methodology for photovoltaics for transfer to the voluntary consensus system for development as American National Standards.

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Current Projects

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Program Assessment and Integration Projects

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ELEMENT: Program Assessment and Integration

Prime Contractor and Address The Aerospace Corporation P.O. Box 92957 Los Angeles, California 90009	Title Photovoltaic Mission Analysis
Principal Investigator Name: Dr. Mason B. Watson Phone: (213) 648-5615	Contract No. EY-76-C-03-1101 Project Agreement 8
Work Location El Segundo, California	Period of Performance December 1975-February 1979
Government Technical Representative and Address Paul Maycock DOE/ETS Washington, D.C. 20545	Fiscal Year 1978 Funding \$200,200
	Cumulative Funding \$1,233,500

Summary

The overall objective of this project was to support the planning, development, and guidance of the DOE National Photovoltaic Program on a continuing basis by: (1) identifying and evaluating those photovoltaic (PV) applications that are most likely to lead to significant contributions to the national energy supply; (2) identifying and evaluating strategies that will stimulate the growth of photovoltaic markets; and (3) providing technical support to the DOE Photovoltaic Program Office.

The approach used in evaluating candidate PV applications has been based on computer simulation of system operation within the constraints of each application. The annual cost of service is then compared with the cost of providing the same service by conventional means. In grid-connected applications, the capital cost of the backup capacity needed in order to maintain utility system reliability is included in the PV capital cost.

Evaluation of PV total energy system applications in single-family residences showed that the breakeven module price can exceed \$1000/kW_{pk} for electricity prices expected in the years 1990 to 2000. A screening of total energy and electric-only applications identified low-rise apartments and pulp mills as attractive candidates for further study. A study of the impact of recent revisions in the insolation data base on analyses of PV power plants showed only small changes in evaluations of flat-plate systems (breakeven module price \$100 to \$300/kW_{pk}). This study also indicated that plants using medium or high concentration will be competitive before the year 2000 only if converter efficiencies can be increased substantially without prohibitive price penalty or if the thermal energy is used profitably. A study of the possibility of subsidizing deployment of PV power plants through increases in customer charges showed that, if DOE module price goals are met, only modest increases in these charges (less than \$25/year for the average residential customers) will permit up to 4 percent of the U.S. electricity needs to be met by PV plants in the year 2000. Other results have included: (1) the development of a computer model of a hybrid high-concentration photovoltaic/thermal-electric power plant for use in future detailed analyses of this novel concept; and (2) the completion of a comparative review of a number of recent ERDA/DOE-sponsored surveys of PV markets.

ELEMENT: Program Assessment and Integration

Prime Contractor and Address The Energy Laboratory Massachusetts Institute of Technology Bldg. E38-411 Cambridge, Massachusetts 02139	Title Support for Institutional Analysis
	Contract No. Under negotiation for work completed to date
	Period of Performance May 1, 1978-July 1, 1978
Principal Investigator Name: A. Massoni Phone: (202) 833-2131	
Work Location Cambridge, Massachusetts and Washington, D.C.	Fiscal Year 1978 Funding Maximum of \$7,000
Government Technical Representative and Address Dr. Harold Macomber Department of Energy/ETS Washington, D.C. 20545	Cumulative Funding

Summary

Work undertaken on this contract was in support of the Institutional Analysis portion of the research at the MIT Energy Laboratory. The objective was design of research methodology to collect information about institutional data relevant to the small-scale daytime radio station experiment underway at the MIT Lincoln Laboratory. As this represented a support contract only, further work and results of the analysis will be an outcome of the Energy Laboratory, not of the Massoni subcontract.

ELEMENT: Program Assessment and Integration

Prime Contractor and Address The Energy Laboratory Massachusetts Institute of Technology Bldg. E38-411 Cambridge, Massachusetts 02319	Title Support for Market Analysis
Principal Investigator Name: Charles E. Allen Phone: (201) 379-1323	Contract No. 33770
Work Location Basking Ridge, New Jersey and Cambridge, Massachusetts	Period of Performance May 1, 1978-May 30, 1979
Government Technical Representative and Address Dr. Harold Macomber Department of Energy/ETS Washington, D.C. 20545	Fiscal Year 1978 Funding \$10,000
	Cumulative Funding \$16,250

Summary

Work undertaken on this contract was in support of market research and analysis in photovoltaics. The work completed during FY 1978 required preparation pretesting, administration coding, and preliminary analysis of survey data on homeowners response to residential photovoltaic power systems. This work was carried out in conjunction with informative displays of residential systems prepared by the MIT Lincoln Laboratory in cooperation with the MIT Energy Laboratory. Data was collected on "Sun Day," May 3, 1978.

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Research and Advanced Development

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ELEMENT: Research and Advanced Development

Prime Contractor and Address Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Title Electrodeposited Amorphous Thin Films for Solar Cell Applications
	Contract No. ET-78-C-03-2215
Principal Investigator Name: Dr. Alfred E. Austin Phone: (614) 424-5395	Period of Performance September 1, 1978-August 31, 1979
	Fiscal Year 1978 Funding \$169,813
Work Location Columbus, Ohio	Cumulative Funding \$169,813
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	

Summary

The objective of this project is to develop the electrodeposition process to produce amorphous silicon solar cells. The approach used in this project includes the following: (1) selection of appropriate dopant compounds, electrolytes, and reduction potentials to produce amorphous silicon with controllable electronic properties; (2) characterization of the physical and electrical properties of doped electrodeposited amorphous silicon; and (3) formation and characterization of Schottky barrier and/or p-n junction solar cells.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Boeing Aerospace Company Seattle, Washington 98124	Title Cadmium Sulfide/Copper Ternary Heterojunction Cell Research
Principal Investigator Name: R. A. Mickelsen Phone: (206) 773-1074	Contract No. EG-77-C-03-1458 Period of Performance September 30, 1977-November 30, 1978
Work Location Seattle, Washington	Fiscal Year 1978 Funding \$177,075
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$254,577

Summary

The objective of this program is to conduct research leading to the development of a stable, polycrystalline, thin-film photovoltaic solar cell of at least 4 cm in area and 8 percent efficiency based upon the CdS/CuInSe₂ material system. The approach used in this project is as follows:

- a. Design and fabricate test structures/devices using vacuum evaporation processes for the semiconductor film deposition onto glass or alumina substrates.
- b. Fabricate and evaluate heterojunction CdS/CuInSe₂ thin-film cells of 1 and 4 cm² in area.
- c. Construct a conceptual model for the CdS/CuInSe₂ solar cell, and for the projection of future cell conversion efficiencies and low-cost production methods.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Brown University Division of Engineering Providence, Rhode Island 02912	Title Cadmium Sulfide/Mixed Copper Ternary Semiconductor Heterojunction Solar Cell Research
	Contract No. EG-77-C-03-1579
Principal Investigator Name: J.J. Loferski and J. Shewchun Phone: (401) 863-2671	Period of Performance September30,1977-September30, 1978
	Fiscal Year 1978 Funding \$227,000
Work Location Providence, Rhode Island	Cumulative Funding \$227,0000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Coloardo 80401	

Summary

Powder samples of the copper ternaries CuInS_2 , CuInSe_2 , CuInTe_2 , AgInS_2 , AgInSe_2 , CuGaS_2 , CuGaSe_2 , of quaternary alloys of the type $\text{CuInSe}_2\text{z Tez}(1-\text{z})$, and of pentenaries of the type $\text{Ag}_x \text{Cu}_{1-x} \text{InS}_2\text{z Se}_2(1-\text{z})$ have been synthesized. The bandgaps E_G of these materials were determined from cathodoluminescence spectra after x-ray diffraction had indicated that the powder contained a single phase. Thin films are being produced from these samples by rf sputtering, ion beam sputtering and resistance heated evaporation. The composition and structure of the films have been determined by EDAX, x-ray diffraction, scanning electron microscopy, and optical transmission.

An acceptable combination of grain size and composition have not yet been achieved. Some heterojunction thin-film devices based on n-CdS and p-type copper ternaries exhibit a photovoltaic effect, but their efficiency is less than 1 percent.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Colorado State University Electrical Engineering Department Fort Collins, Colorado 80523	Title Degradation of ITO/Silicon Solar Cells
Principal Investigator Name: C.W. Wilmsen Phone: (303) 491-6015	Contract No. EG-77-S-02-4524 Period of Performance June 1, 1977-July 1, 1978
Work Location Fort Collins, Colorado	Fiscal Year 1978 Funding \$59,517
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$59,517

Summary

The objective of this project was to determine the degradation mechanisms which reduce the output power and lifetime of Indium Tin Oxide (ITO) silicon solar cells. The approach required the contractor to:

- a. Implement changes in ITO/silicon solar cell electrical characteristics during load testing under normal and accelerated conditions.
- b. Implement chemical composition and bonding changes of the ITO film and the ITO-silicon interface that result from the load testing.
- c. Correlate the chemical composition/bonding and electrical changes in order to determine the degradation and failure mechanisms.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Colorado State University Electrical Engineering Department Fort Collins, Colorado 80523	Title Oxide Semiconductor on Silicon (OSOS) Solar Cells
	Contract No. EG-77-S-02-4524
Principal Investigator Name: Joel DuBow Phone: (303) 491-8325-	Period of Performance June 1, 1977-May 31, 1978
Work Location Fort Collins, Colorado	Fiscal Year 1978 Funding \$218,060
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$218,060

Summary

The objective of this project was to conduct studies leading to a low-cost, high-energy, conversion-efficient, long-life photovoltaic cell using thin films of oxide semiconductors on various forms of silicon. The approach entailed the following tasks:

- a. Fabricating efficient large-area Oxide Semiconductor On Silicon (OSOS) solar cells using single crystal silicon.
- b. Fabricating efficient OSOS solar cells using polycrystalline and amorphous silicon.
- c. Investigating the use of oxides other than Indium Tin Oxide (ITO).
- d. Evaluating the major limitations to cell performance and the effects of processing modifications upon cell performance using electronic and analytic characterization techniques.
- e. Modeling theoretically, the performance of OSOS solar cells on amorphous and polycrystalline substrates.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Delaware Institute of Energy Conversion Newark, Delaware 19711	Title Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research
Principal Investigator Name: John D. Meakin Phone: (302) 995-7155	Contract No. D.O.E. EG-77-C-03-1576 S.E.R.I. RD-8-1625
	Period of Performance July 1, 1977-September 30, 1978
Work Location Wilmington, Delaware	Fiscal Year 1978 Funding \$618,989
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$776,059

Summary

The objective of this project was to produce thin-film polycrystalline solar cells based on the CdS/Cu₂S junction with energy conversion efficiencies of at least 10 percent and expected degradation rates of less than 5 percent in 20 years. The efficiency improvement efforts on this program were directed by loss minimization analysis. 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 four tasks: (1) development of improved efficiency of CdS/Cu₂S cells; (2) development of cells based on the (CdZn)S/Cu₂S junction with enhanced open-circuit voltages and higher efficiencies than are possible with CdS/Cu₂S; (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; and (4) development of an encapsulation system to provide complete hermetic sealing giving the required degree of solar cell durability.

Textured CdSCu₂ cells of 9.15 percent energy conversion efficiency in sunlight have been made. Planar junction cells are expected to exceed 10 percent conversion efficiency.

Substituting (CdZn)S for CdS increases the open-circuit voltage and up to 0.7 V has been achieved. Mixed sulfide films (0.25 percent Zn) have been grown of uniform and controlled composition. The resistivity can be set at the desired value of ~ 1 to 10 Ω cm without the addition of extrinsic dopants. Cells with currents of 18 mA/cm² and open circuit voltages of 0.60 V have been made with estimated sunlight efficiencies of ~ 7 percent.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Delaware Institute of Energy Conversion Newark, Delaware 19711	Title Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research
Principal Investigator Name: John D. Meakin Phone: (302) 995-7155	Contract No. D.O.E. EG-77-C-03-1576 S.E.R.I. RD-8-1625
	Period of Performance July 1, 1977-September 30, 1978
Work Location Wilmington, Delaware	Fiscal Year 1978 Funding \$618,989
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$776,059

Summary (continued)

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 encapsulation and durability task has established the key role played by oxidation of the Cu₂S layer. Development of multilayer antireflection coatings and encapsulants has been started. Various deposition techniques are being explored.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Delaware Institute of Energy Conversion Newark, Delaware 19711	Title Improved Semiconductors for Photo-voltaic Cells - Zn_3P_2
	Contract No. EX-76-C-01-2460
Principal Investigator Name: Anthony Catalano Phone: (302) 995-7155	Period of Performance June 18, 1976-September 30, 1978
Work Location Wilmington, Delaware	Fiscal Year 1978 Funding \$225,920
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$506,836

Summary

The objective of this project was to evaluate Zn_3P_2 as a new material for low-cost, high-efficiency, terrestrial photovoltaic cells.

The approach used in this research has been: (1) the development of a process to synthesize Zn_3P_2 ; (2) the development of a method for the growth of large crystals of Zn_3P_2 , suitable for prototype device fabrication; (3) the development of a method for the preparation of thin polycrystalline films on suitable substrates; (4) the evaluation of the necessary optical, electrical, structural, and mechanical properties of single crystals and thin films; and (5) the fabrication and testing of Schottky barrier devices as a guide to the development of high-efficiency cells.

The following accomplishments are noted: (1) Zn_3P_2 has been routinely synthesized by direct combination of the high purity elements; (2) single and multiple crystal boules of Zn_3P_2 1 cm in diameter and 3 cm long have been grown by vapor transport; (3) thin polycrystalline films have been grown by vacuum evaporation and close space transport; (4) Zn_3P_2 is normally a p-type semiconductor, whose room temperature resistivity can be adjusted from nominally 10^5 - $10\Omega\text{-cm}$ by equilibration at the appropriate phosphorus pressure; (5) a quantitative expression relating room temperature carrier concentration to phosphorus partial pressure and anneal temperature indicates the dominant electrically active defects are phosphorus interstitials; (6) minority carrier (electron) diffusion lengths as long as $6\mu\text{m}$ have been observed; (7) the optical bandgap of Zn_3P_2 is nominally 1.5 eV, near the value expected for maximum solar energy conversion efficiency; (8) transparent metal film Schottky barrier devices have been fabricated which yield conversion efficiencies of 1.7 percent (No A-R, ELH-AM1-100 mW/cm²); and (9) Schottky barrier devices employing a stripe geometry have shown conversion efficiencies as high as 6.08 percent (uncorrected) and 7.6 percent (corrected for grid blockage) with a single layer SiO A-R (ELH-AM1-100 mW/cm²).

ELEMENT: Research and Advanced Development

Prime Contractor and Address Exxon Research and Engineering Company Government Research Laboratories P.O. Box 8 Linden, New Jersey 07036	Title Heterostructure Single-Crystal Silicon Photovoltaic Solar Cell (SnO ₂)
Principal Investigator Name: Amal K. Ghosh Phone: (201) 474-3465	Contract No. EY-76-C-1283 Ext. of Contract No. E(04-5)-1283
	Period of Performance May 15, 1978-August 10, 1978
Work Location Linden, New Jersey	Fiscal Year 1978 Funding \$71,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$316,837

Summary

The objective of this project was to conduct studies leading to low-cost, high-efficiency, and long-life heterostructure SnO₂/Si solar cells. The approach entailed the following tasks:

- Fabricating SnO₂/Si solar cells by electron beam disposition and spraying of SnO₂.
- Evaluating the structural, electrical, and optical properties of the resulting photovoltaic device.
- Theoretical modeling which would predict maximum device efficiency and suggest means of improving efficiency.
- Conducting an experimental study of device lifetime and stability.
- Analyzing and projecting future costs of large-scale quantities of SnO₂/Si solar cells.

The results achieved are as follows:

- Efficiency of solar cells: single crystal was 12.24 percent SnO₂/Si and 10 percent ITO/Si; polycrystal was 10 percent Si/SnO₂. All for AM1 irradiance, areas >1 cm².
- After evaluating structural, electrical, and optical properties of SnO₂/Si cells, a theoretical model was presented which predicts a maximum theoretical efficiency of 20 percent.
- The theory also suggested means of improving efficiency from the present 12.24 percent value. After a drop of less than 10 percent of its initial value the device stabilized itself. Cost of process of SnO₂/Si cells was consistent with the DOE projected goal of \$.50/peak watt.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Florida Engineering and Industrial Experiment Station Gainesville, Florida 32611	Title Physical Models for Thin- Film Polycrystalline Solar Cells Based on Measured Grain-Boundary and Elec- tronic Parameter Properties
Principal Investigator Name: Fredrik A. Lindholm Phone: (904) 392-4929	Contract No. ET-78C-01-3421 Period of Performance September 18, 1978-September 17, 1979
Work Location Gainesville, Florida	Fiscal Year 1978 Funding \$130,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$130,000

Summary

The overall objective of this program is to develop theoretical physical models that link the power conversion efficiency, open circuit voltage, short circuit current, and fill factor to the dominant physical mechanisms in polycrystalline thin-film solar cells. The approach will reduce the three-dimensional boundary value problem associated with real inhomogeneity and grain boundary recombination to a related one-dimensional problem yielding a one-dimensional approximate model. The approaches used in this project include the following:

- a. Consider the following dominant physical mechanisms: distorted energy bands, inter- or intra-band transitions or recombination rates, surface recombination at the non-metallized illuminated surface, grain boundary effects, positional dependencies, and dependence of parameters on illumination and injection levels.
- b. Determine the three-dimensional morphology and composition of grain boundaries through Auger spectroscopy, SIMS, SEM, TEM, and EBIC.
- c. Characterize the electrical mechanisms through appropriate measurements.
- d. Correlate the electrical properties with the morphology and composition.
- e. Measure the dependence of the minority carrier lifetime, effective mobility, and intra-grain lifetime on illumination level.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Florida Electrical Engineering Department Gainesville, Florida 32611	Title Studies of Basic Mechanisms Influencing Solar Cell Efficiency for Terrestrial Applications
	Contract No. EY76-S-05-5134
Principal Investigator Name: F. A. Lindholm Phone: (904) 392-4929 or (904) 392-4924	Period of Performance March 1, 1978-September 30, 1978
Work Location Gainesville, Florida	Fiscal Year 1978 Funding \$89,370
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$299,486

Summary

The objectives of this research were as follows:

- To determine and describe the basic mechanisms that control and limit solar cell power conversion efficiency.
- To develop mathematical models that enable the inclusion of these mechanisms in the engineering design of solar cells.
- To explore design improvements based on the understanding gained of the basic mechanisms.

Basic mechanisms determine the transport, recombination, and generation of electrons and holes in semiconductor material, and, thereby, in large measure, determine the solar conversion efficiency.

To meet the described objective, the research focused on the following:

- Mechanisms which control the electronic parameters, such as lifetime and effective bandgap.
- Transport, recombination, and generation processes characterization.
- Basic mechanisms by which such design variables such as injection level, doping profile, and device structure influence these processes.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Florida Electrical Engineering Department Gainesville, Florida 32611	Title Studies of Basic Mechanisms Influencing Solar Cell Efficiency for Terrestrial Applications
	Contract No. EY76-S-05-5134
Principal Investigator Name: F. A. Lindholm Phone: (904) 392-4929 or (904) 392-4924	Period of Performance March 1, 1978-September 30, 1978
Work Location Gainesville, Florida	Fiscal Year 1978 Funding \$89,370
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$299,486
Summary (continued)	

The main results achieved during the nine-month duration of this award are the following:

- a. Development of a new and more accurate method for determining energy bandgap narrowing in the highly doped emitter region of p-n junction silicon solar cells. The method is based on the temperature dependence of the emitter component of the dark I-V characteristic.
- b. Experimental demonstration of the importance of the surface recombination velocity in determining V_{oc} of diffused p-n junction silicon solar cells.
- c. Detailed device physics underlying design modifications that have produced high V_{oc} and high efficiency (18.5 percent) silicon cells for concentration ratios from 25 to 50.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Hughes Research Laboratories 3011 Malibu Canyon Road Malibu, California 90265	Title Photovoltaic Mechanisms in Polycrystalline Thin-Film Solar Cells
	Contract No. ET-78C-01-3412
Principal Investigator Name: R. Knechtli Phone: (213) 456-6411 Ext. 252	Period of Performance September 27, 1978-September 26, 1979
Work Location Malibu, California	Fiscal Year 1978 Funding \$119,998
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$119,998

Summary

The objectives of this program are to increase the understanding of the fundamental mechanisms that determine the photovoltaic conversion efficiency of polycrystalline thin film solar cells by investigating theoretically and experimentally the effect of the electronic characteristics of the grain boundary on the open circuit voltage (V_{oc}) in homojunctions and in heteroface-homojunction and heterojunction solar cells. The practical objective of the program is to enhance cell efficiency through passivation of the grain boundaries.

The approach used in this project includes the following:

- Develop in more detail the band model in which grain boundary regions are represented on thin sheets of lower bandgap semiconductor between higher bandgap grains.
- Experimentally, determine the effective bandgap, barrier height at grain boundaries and density of states in the vicinity of grain boundaries in n- and p-type InP (and GaAs).
- Prepare homojunctions in polycrystalline InP and measure the photoresponse of the diodes as a function of photon energy.
- Evaluate techniques for passivation of grain boundaries in InP homojunctions through: (1) selective diffusion of Ga to form $\text{In}_x\text{Ga}_{1-x}\text{P}$ increasing the bandgap in the grain boundary region; (2) tying up dangling bonds through diffusion of H, Li, or F to remove recombination states; and (3) anodic oxidation to physically separate the n-type and p-type material at the grain boundary.
- Evaluate the effectiveness of the passivation through electrical and optical measurements.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Hughes Research Laboratories A Division of Hughes Aircraft Company 3011 Malibu Canyon Road Malibu, California 90265	Title Thin-Film Indium Phosphide (InP)/Cadmium Sulfide (CdS) Terrestrial Solar Cells
Principal Investigator Name: K. Zanio and L. Fraas Phone: (213) 456-6411	Contract No. EY-76-C-04-3717 Period of Performance September 1976-September 1978
Work Location Malibu, California	Fiscal Year 1978 Funding \$215,100
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$413,593

Summary

The overall objective of this program was to develop the indium phosphide/cadmium sulfide (InP/CdS) heterojunction pair as an economical all-thin-film terrestrial solar cell. An economical all-thin-film cell structure consists of InP-on-CdS-on-glass with the InP prepared at low temperature (2500 to 3500°C) by the Planar Reactive Deposition (PRD) approach. Intermediate objectives consisted of establishing the PRD approach as a viable low temperature process and preparing conventional CdS-on-InP-single-crystal cells to evaluate the InP layers and determine the effects of grain boundaries on cell performance. Therefore, single-crystal thin films of InP were prepared on semi-insulating substrates at 4000°C with the PRD approach. Undoped films were n-type with room-temperature mobilities as high as $4062 \text{ cm}^2/\text{Vsec}$, corresponding to a residual active impurity content of a few times 10^{16} cm^{-3} . This mobility is higher than mobilities for films prepared by either molecular-beam epitaxy or metal-organic chemical vapor deposition. P-type doping was achieved by incorporating an In:Al:Be alloy in the Knudsen cell. Single-crystal cells were prepared by depositing CdS onto single crystals of commercial p-type InP and onto intermediate layers of p-type InP, the latter deposited earlier onto the commercial InP substrates at 4000°C by the PRD approach. The efficiency of the best reference cells and the cells using the intermediate PRD thin film as the light absorbing layer were similar, being approximately 10.5 percent (Air-Mass 2 without antireflection coatings). Preliminary studies on polycrystalline solar cells prepared by the deposition of CdS onto intermediate polycrystalline InP layers show reduced efficiencies, primarily through a decrease in the open-circuit voltage, V_{oc} . In order to reconcile differences between the single crystal and polycrystalline results, a new grain boundary model was developed. The grain boundary is represented as a thin sheet of lower bandgap semiconductor material sandwiched between the higher bandgap grains. The resulting higher leakage currents across the p-n junctions at the grain boundaries requires that V_{oc} be increased by increasing the grain size and/or passivating the grain boundaries.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Jet Propulsion Laboratory California Institute of Technology Pasadena, California	Title High-Efficiency Thin-Film Gallium Arsenide Solar Cells
	Contract No. Interagency Agreement EG-77-A-29-1074
Principal Investigator Name: Richard J. Stirn Phone: (213)354-4678	Period of Performance March 1, 1977-February 28, 1979
Work Location Pasadena, California	Fiscal Year 1978 Funding \$322,320
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$686,066

Summary

The objective of this task is to develop a thin-film polycrystalline gallium arsenide (GaAs) solar cell with conversion efficiency greater than 15 percent and cell cost under \$0.50 per peak watt. The structure being investigated uses as a low-cost substrate a germanium (Ge) layer deposited by evaporation or by chemical vapor pyrolysis on an appropriately coated steel substrate, and subsequently recrystallized by a scanning laser beam. GaAs is epitaxially grown on the greatly enlarged grains of Ge using metal-organic gallium sources and arsine transported with hydrogen gas. Prior to development of p/n junction solar cells on these GaAs films, the JPL-developed Antireflecting Metal-Oxide-Semiconductor (AMOS) Schottky barrier structure is being used to fabricate moderately efficient solar cells. A subcontract was recently begun with Chemetal Corp. to investigate very thin tungsten coatings on low-carbon steel using chemical vapor deposition. Earlier work on bulk tungsten substrates showed that grain sizes up to 1-cm in length could be developed with laser beam processing. GaAs films grown by Rockwell International on subcontract on such Ge films have been p-type, rather than the required n-type, apparently due to copper contamination from the e-gun hearth. An in-house GaAs growth facility has been assembled to continue the investigation. Alternative interfacial oxide layers have been studied using laser evaporation techniques in an attempt to improve high temperature stability of AMOS solar cells. No improvement over the native oxide grown by water vapor saturated oxygen was found, although Ga out-diffusion from the GaAs may be a dominant effect. Flash evaporated silver-gallium alloys will be investigated to minimize Ga out-diffusion.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Johns Hopkins University Applied Physics Laboratory Johns Hopkins Road Laurel, Maryland 20810	Title Vacuum-Deposited Polycrystalline Silicon Films for Solar Cell Applications
	Contract No. EY-78-A-03-2208
Principal Investigator Name: C. Feldman Phone: (301) 953-7100	Period of Performance September 1, 1978-August 31, 1979
Work Location Laurel, Maryland	Fiscal Year 1978 Funding \$173,900
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$173,900

Summary

The objective of this project is to improve the structural and electrical properties of vacuum-deposited polycrystalline silicon for use in thin-film solar cells. The approach includes the following tasks.

- a. Electron-beam evaporation of polycrystalline silicon films.
- b. Improvements in grain size and quality through control of:
 - deposition rate
 - substrate temperature
 - nucleation rate (e.g., by mechanical limitations)
 - ambient gases.
- c. Experiments on vacuum deposition of conduction bottom electrodes (e.g., borides, silicides) on low-cost glassy substrates.
- d. Investigations of recrystallization by thin-layered alloy movement.
- e. Characterization of structural, chemical, and electrical quality of the silicon films.
- f. Fabrication of solar cells by standard diffusion techniques.
- g. Measurements of solar cell parameters and correlations with grain structure of films.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Lawrence Livermore Laboratory University of California Livermore, California 94550	Title Reactively Sputtered Thin-Film Cu ₂ S/CdS Solar Cells
	Contract No. W-7405-ENG-48
Principal Investigator Name: G. Armantrout Phone: (415) 447-1100	Period of Performance October 1, 1977-September 30, 1978
Work Location Livermore, California	Fiscal Year 1978 Funding \$150,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$300,000

Summary

The objective is to develop a stable, high-efficiency thin-film CdS-Cu₂S cell by reactive sputtering techniques. The approach entails applying multiple sputtering techniques to form low-cost, high-performance thin-film photovoltaic devices from materials used in existing single and polycrystalline solar cells. Analysis is being made of the quality of the CdS-Cu₂S heterojunction formed by the reactive sputtering process. In addition, an effort is being made to make use of the process flexibility to optimize the heterojunction characteristics. Specifically, the following tasks are required to meet the described objective:

- a. Achieve reproducible CdS layers by sputtering and thermal evaporation methods for better characterizations of the heterojunctions.
- b. Concentrate on studying and controlling the Cu₂S-CdS interface by CdS surface treatments, substrate temperature control, and sputtering parameter variations.
- c. Experiment with topotaxial formations of Cu₂S on CdS to achieve optimum junction characteristics for high-efficiency photovoltaic cells. The formation of near chalcocite films by reactive sputtering process has been achieved. Advantages of this new dry Cu₂S formation process are now being systematically explored.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Lawrence Berkeley Laboratory University of California Berkeley, California 94550	Title Research on $\text{Cu}_2/(\text{Cd,Zn})\text{S}$ Photo- voltaic Solar Energy Converters
	Contract No. W-7405-ENG-48
Principal Investigator Name: Jack Washburn Phone: (415) 843-2740	Period of Performance April 1, 1977-October 1, 1978
Work Location Berkeley, California	Fiscal Year 1978 Funding \$55,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$145,000

Summary

The objective of this project is to better understand the nature of $\text{Cu}_2-(\text{Cd,Zn})\text{S}$ hetero-structure in order to identify those factors which will ultimately limit the efficiency and stability of devices based on this structure. This approach includes the following tasks:

- Development of a vacuum deposition method for fabricating single-crystal thin films of $(\text{Cd,Zn})\text{S}$.
- Evaluation and correlation of the electrical and physical properties of these films.
- Conversion of a layer of the $(\text{Cd,Zn})\text{S}$ films to Cu_2S together with electrical and physical characterization (the latter via high-resolution-transmission electron microscopy) of the resultant copper sulfide.
- Fabrication of heterostructures from the single crystal $(\text{Cd,Zn})\text{S}$ films as research tools to imitate the structure of conventional films $(\text{Cd,Zn})\text{S}$ cells without the complication of grain boundaries.
- Correlation of electrical measurements and physical properties of these test devices to establish the relationship between the defect structure and electrical behavior of $\text{Cu}_2\text{S}-(\text{Cd,Zn})\text{S}$ heterojunctions.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Lockheed Palo Alto Research Laboratory Palo Alto, California 94304	Title Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research
Principal Investigator Name: William W. Anderson Phone: (415) 493-4411	Contract No. EG-77-C-03-1459 Period of Performance September 30, 1977-November 30, 1978
Work Location Palo Alto, California	Fiscal Year 1978 Funding \$288,200
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$288,200

Summary

This program is an investigation of the application of the post-magnetron reactive sputtering process to the production of solar cell quality thin films of CdS/Cu₂S for large-scale terrestrial photovoltaic energy conversion.

Studies are being conducted in the following technical areas:

- Investigation of the deposition parameters required to obtain high quality films of Cd_{1-x}Zn_xS and Cu₂S on glass and multilayer substrates.
- Characterization of the structural, electrical, optical, and photoelectronic properties of the Cd_{1-x}Zn_xS, and Cu₂S films and the resulting Cd_{1-x}Zn_xS/Cu₂S junction as a function of deposition parameters.
- Fabrication of Cd_{1-x}Zn_xS/Cu₂S heterojunction solar cells and evaluation of the electrical and optical properties of these cells.

The parametric dependence of CdS and Cu₂S properties on deposition conditions have been determined. Multi-layer Al/In/CdS/Cu₂S structures have been deposited in a multi-cathode system without breaking the vacuum. Photovoltaic properties of the resultant heterojunction are being studied.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Lincoln Laboratory Massachusetts Institute of Technology Lexington, Massachusetts 02173	Title GaAs Thin-Film Solar Cells
Principal Investigator Name: John C. C. Fan Phone: (617) 862-5500 (x5474)	Contract No. EX-76-A-01-2295 Period of Performance September 28, 1977-September 27, 1978
Work Location Lexington, Massachusetts	Fiscal Year 1978 Funding \$219,899
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$219,899

Summary

The objective of this program is to develop efficient, low-cost Gallium Arsenide (GaAs) thin-film solar cells. The program initially addressed the two principal problems involved in the fabrication process: preparation of large-grained GaAs films and formation of barriers for charge separation. The approach entailed conducting studies under the following technical areas:

- a. The development of techniques for the deposition of amorphous GaAs films on low-cost substrates which are also suitable for use in the recrystallization process.
- b. The development of laser beam shaping and scanning techniques, to grow large crystallites in amorphous and polycrystalline films of GaAs.
- c. The development of Chemical Vapor Deposition (CVD) techniques for depositing large-grain polycrystalline GaAs films on low-cost substrates.
- d. The characterization of the structural, electrical, and optical properties of these films.
- e. The preparation of thin-layer homojunction solar cells of GaAs by CVD on these films.
- f. The preparation of conducting oxide/GaAs heterojunction solar cells on single crystal GaAs and the large-grained GaAs films.
- g. The characterization of the electrical and optical properties of these junctions.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Midwest Research Institute, SERI Division 1536 Cole Boulevard Golden, Colorado 80401	Title Photovoltaics Technology
Principal Investigator Name: Dr. D. L. Feucht/Dr. S. Wagner Phone: (303) 231-1373 303) 231-1105	Contract No. EG-77-C-01-4042 Period of Performance October 1, 1977-September 30, 1978
Work Location Golden, Colorado	Fiscal Year 1978 Funding \$2,426,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$2,426,000

Summary

A major effort of the Department of Energy National Photovoltaic Program is currently directed towards the relative commercial applications of concentrator systems and single-crystal silicon flat-plate arrays. However, a wide variety of other known photovoltaic material exists, with the potential for providing solar arrays at significantly lower prices.

The major thrust of the Photovoltaic R&D Program is to develop these options to the point that they can be judged on the basis of electricity cost which is a function of conversion efficiency, array cost, stability, life, and producibility.

At present the program is directed to investigations of photovoltaic concepts, materials, and solar cell structures. It emphasizes thin-film structure for low-cost solar cells through:

- a. Material conservation.
- b. Simplified techniques.
- c. Inexpensive substrates.

Simplified growth techniques and inexpensive substrates imply polycrystalline and amorphous films, and probably impurity concentrations higher than encountered in semiconductor materials used in the electronic industry. At the same time, these structures must demonstrate a potential for high conversion efficiency.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Midwest Research Institute, SERI Division 1536 Cole Boulevard Golden, Colorado 80401	Title Photovoltaics Technology
Principal Investigator Name: Dr. D. L. Feucht/Dr. S. Wagner Phone: (303) 231-1373 (303) 231-1105	Contract No. EG-77-C-01-4042 Period of Performance October 1, 1977-September 30, 1978
Work Location Golden, Colorado	Fiscal Year 1978 Funding \$2,426,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$2,426,000
Summary (continued)	

The Photovoltaic R&D Program has been structured to include the following activities:

a. Advanced Materials/Cell Research

- Cu₂S/CdS
- Cuternary/CdS
- thin-film polycrystalline GaAs
- polycrystalline silicon
- amorphous silicon.

b. High-Risk R&D Research

- emerging materials (Cu₂O, Zn₃P₂, ZnSiAs₂, CdTe)
- advanced concentrator (multijunction cells, luminescence collector)
- electrochemical photovoltaic cells
- innovative concepts.

c. Fundamental Support Research

- material properties
- device mechanisms
- cell evaluation techniques.

The above activities were carried out at various universities, National laboratories, and private companies. In-house research at SERI was also initiated.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Mobil Tyco Solar Energy Corporation 16 Hickory Drive Waltham, Massachusetts 02154	Title Amorphous Silicon Thin-Film Heterojunction Solar Cells
	Contract No. ET-78-C-03-1846
Principal Investigator Name: Dr. R. O. Bell Phone: (617) 890-0909	Period of Performance September 1, 1978-August 31, 1979
Work Location Waltham, Massachusetts	Fiscal Year 1978 Funding \$91,204
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$91,204

Summary

The goal of this project is to improve the conversion efficiency of solar cells formed on hydrogenated amorphous silicon. The approach entails conducting studies to:

- a. Improve the minority carrier diffusion length in hydrogenated amorphous silicon films by substitution of carbon, tin, germanium, or alkali metals during glow discharge deposition.
- b. Improve both the light input into the active cell material and the fill factor of the resulting cells by preparing heterojunctions using a transparent semiconductor window on the amorphous silicon.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Monosolar, Inc. 100 Wilshire Boulevard, Suite 600 Santa Monica, California 90401	Title Electrodeposition of CdTe Solar Cells
Principal Investigator Name: Robert L. Rod, Ph.D., P.E. Phone: (213) 451-8151	Contract No. EX-76-C-01-2457
Work Location Inglewood, California	Period of Performance August 1, 1977-July 15, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$169,996 + \$1 Fixed Fee
	Cumulative Funding \$296,986 + Fixed Fees

Summary

The objective of the program ultimately was to produce large-area, 10-percent-efficient thin-film polycrystalline solar cells by electrochemical deposition of cadmium telluride. The first effort, now complete, required development of the underlying theory controlling the electrodeposition of a compound semiconductor simultaneously with the particular donor or acceptor for the n- and p-layer(s) as needed.

Best results have been obtained recently with the heterojunction

Soda glass substrate/n-In_{0.3}Sn/p-CdTe:As/p-Te

Samples of this kind can be made routinely up to 3 x 3 inches in size. As of now, best results have been obtained by using a multiplicity of small black dot contacts of Ag which measure approximately 1 mm² in area. Full coverage over the available 9 in.² surface, or greater if desired, awaits correction of pinholes that apparently are present in the CdTe film and possibly the underlying ITO. Typical CdTe film thickness is from 0.1 to 0.2 micron, while the ITO layer applied to glass by either PPG Industries or another supplier is about 0.5 microns in thickness.

Results to date with a Xenon lamp solar simulator show $V_{oc}=0.45-0.5V$, $J_{sc}=7-11 \text{ mA/cm}^2$ and F.F. up to around 0.4 with a solar flux of 85 mW/cm². This is equivalent to efficiencies as high as 3 percent. Studies just commenced show that the response is mainly in the blue because of the very thin CdTe film presently used and that a substantial efficiency gain can be realized when a thicker CdTe layer can be electroplated. Efficiency improvements also are expected shortly when pinholes are reduced in number and series resistance of the entire device is lowered.

Analysis of production costs for this device show that with relatively inexpensive equipment and reagent grade chemicals, these electroplated cells up to a foot square can be made for under 20¢/peak watt once 10 percent efficiency is achieved.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Motorola, Inc. Solar Energy Department Phoenix, Arizona 85008	Title Thin Films of Silicon on Low-Cost Substrates
	Contract No. EY-76-C-03-1287
Principal Investigator Name: K. R. Sarma Phone: (602) 244-5631	Period of Performance July 13, 1977-August 31, 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$256,320
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$493,770

Summary

The objective of this research project was to investigate a low-cost, energy-efficient method for producing thin films of silicon suitable for the fabrication of greater than 10 percent efficient solar cells. To meet the above objective, the approach was to:

- a. Deposit microcrystalline silicon films by introducing SiHCl_3 or SiCl_4 into an RF plasma produced by an Energy Beam onto Mo or W temporary substrate.
- b. Separate the deposited silicon film from the temporary substrate by the Thermal Expansion Shear Separation (TESS) technique.
- c. Recrystallize the separated microcrystalline silicon film using scanned laser beams to produce single-crystal or macrocrystalline silicon films and fabricate solar cells using these grain-enhanced films.

During this contact period, (1) microcrystalline silicon films were successfully deposited, efficiently using the Energy Beam and separated from the Mo substrate by the TESS technique; (2) reusability of Mo substrates were demonstrated; and (3) initial solar cells were fabricated on the laser crystallized silicon films which exhibited efficiencies of over 6 percent.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Motorola, Inc. Solar Energy Department Phoenix, Arizona 85040	Title Thin-Film Polycrystalline Silicon Solar Cells
	Contract No. ET-78-C-03-2207
Principal Investigator Name: Dr. K. Sarma Phone: (602) 244-6900	Period of Performance September 1, 1978-August 31, 1979
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$290,137
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$290,137

Summary

The objective of this research project is to investigate a low-cost, energy-efficient method for producing thin films of silicon suitable for the fabrication of greater than 10 percent efficient solar cells.

The approach used in this project will:

- a. Optimize parameters for energy beam deposition of small-grain, high tensile strength silicon films.
- b. Investigate Mo and W substrates to determine the quality of thermal expansion sheet separation, effects on the silicon films, and potential for re-use.
- c. Characterize the structural, compositional, and electrical properties of the films.
- d. Recrystallize the polycrystalline silicon films using a scanned laser beam.
- e. Fabricate solar cells by ion implantation and diffusion.

ELEMENT: Research and Advanced Development

Prime Contractor and Address National Bureau of Standards Electron Devices Division (721) Washington, D.C. 20234	Title A Program on Solar Cell Measurement Technique Development
	Contract No. Task Order A054-SE of Interagency Agreement EA-77-A-01-6010
	Period of Performance September 15, 1977-October 1, 1978
Principal Investigator Name: Dr. David E. Sawyer Phone: (301) 921-3621	
Work Location Gaithersburg, Maryland	Fiscal Year 1978 Funding \$226,900
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$226,900

Summary

The main objective of this project was to develop improved solar cell measurement technology. The approach involved obtaining spatial point-by-point information about cell design, fabrication, and operation using a laser flying-spot scanner and scanning techniques developed at the National Bureau of Standards (NBS).

A technique simpler than one using microwave-modulated scanning light originally thought to be necessary has been developed to reveal cell operating details. The new technique employs scanning while the cell is forward biased either by a steady-state light source, or an externally supplied dc current. The technique is nondamaging; it requires no electrical contacts to the cell other than those already present, and it can be used on cells in almost any laboratory or test environment. A variety of cell types, including flat-plate Si, GaAs concentrators, GaAs MIS structures, and a polycrystalline Si cell have been scanned to reveal details of cell operation and/or cell defects. Defects previously pinpointed using time-consuming optical inspection methods were readily confirmed using the NBS method. In some cases, cracks previously located were shown by the new method to be longer than indicated optically. Some cells certified as "perfect" were shown by the scanner to contain cracks. Breaks in "finger" metallization are easily found. For one cell, the ohmic contact between the surface metallization fingers and the underlying semiconductor was found to be faulty in several regions to contribute toward a higher-than-designed cell series resistance. This particular defect type cannot be pinpointed with previous art inspection methods. Construction of equipment and development of ancillary techniques required for effective solar cell scanning and for quantification of scanning results is underway. Cells with diameters up to 4" may now be scanned all at once. A novel low-noise, high-intensity source for biasing cells optically has been completed. Reference Structures (RSs) have been designed. These are miniature Si solar cells, some of which contain various accurately designed "defects"; all are accompanied by test patterns for an

ELEMENT: Research and Advanced Development

Prime Contractor and Address National Bureau of Standards Electron Devices Division (721) Washington, D.C. 20234	Title A Program on Solar Cell Measurement Technique Development
	Contract No. Task Order A054-SE of Interagency Agreement EA-77-A-01-6010
	Period of Performance September 15, 1977-October 1, 1978
Principal Investigator Name: Dr. David E. Sawyer Phone: (301) 921-3621	
Work Location Gaithersburg, Maryland	Fiscal Year 1978 Funding \$226,900
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$226,900
Summary (continued)	

independent assessment of cell and "defect" parameters. A subcontract has been let to the University of Southern California at Los Angeles for mathematical modeling of cells containing defects to be coupled with the RS scanning results. Other project activities include the Stability of (Thin-Film) Solar Cells and Materials Workshop held at NBS, May 1-3, 1978, and the planning of a workshop on Photovoltaic Material and Devices scheduled to be held in June 1979.

ELEMENT: Research and Advanced Development

Prime Contractor and Address North Carolina State University Electrical Engineering Department Raleigh, North Carolina 27607	Title The Study of II-IV-V ₂ Chalcopyrite Semiconductors for Solar Cell Applications
	Contract No. EX-76-C-01-2458
Principal Investigator Name: Dr. M. A. Littlejohn Phone: (919) 737-2330	Period of Performance September 1, 1976-July 1, 1978
Work Location Raleigh, North Carolina and Research Triangle Park, North Carolina	Fiscal Year 1978 Funding \$132,639
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$280,389

Summary

The objective of this program was to determine the properties and suitability of the II-IV-V₂ chalcopyrite semiconductors as solar cell materials. These materials are structural analogs to the III-V semiconductors, having similar electrical and optical properties. At the same time the chalcopyrites use less critical constituents than the III-V compounds, and thus they offer the possibility of providing more economical materials for photovoltaics.

To meet the described objective, the following specific areas were studied:

- The vapor phase growth of thin epitaxial films of chalcopyrites ZnSiAs₂ and CdSiAs₂ on appropriate substrates.
- The fabrication of Schottky barrier, heterojunction, and homojunctions formation techniques.
- The evaluation of the resulting material and cell properties.
- An evaluation of the suitability of these materials for solar cells.

ELEMENT: Research and Advanced Development

Prime Contractor and Address RCA Corporation RCA Laboratories Princeton, New Jersey 08540	Title Amorphous Silicon Solar Cells
Principal Investigator Name: David E. Carlson Phone: (609) 452-2700, Ext. 3205	Contract No. EY-76-C-03-1286
Work Location Princeton, New Jersey	Period of Performance June 30, 1976-September 30, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$299,920
	Cumulative Funding \$981,824

Summary

The long-term goal of this project was to produce stable, low-cost (<\$0.50/pW) amorphous silicon solar cells. The objective for the second year was to improve the conversion efficiency to 8 percent (from 6 percent).

A comprehensive research program involved close coordination between fabrication of a-Si:H films and devices, characterization of the same, and theoretical modeling.

A new type of a-Si:H solar cell has been developed using a Pt-SiO₂ cermet as a contacting layer to the a-Si:H. This type of cell can be fabricated entirely in a glow discharge/sputter deposition system, and efficiencies of ~2.4 percent have been observed in large area cells (10 to 40 cm²). The diffusion of deuterium in a-Si:H indicates that the out-diffusion of hydrogen will not cause degradation until after more than 10⁴ years at 100°C. Doping studies have shown that uniform doping levels as low as PH₃/SiH₄ ≈ 10⁻⁵ in the discharge can cause significant reductions in both J_{SC} and V_{OC} of Schottky barrier devices. The decay of transient currents in diodes has been used to estimate a trap density of 10¹⁶ eV⁻¹ cm⁻³ over an energy range of ~0.35 to 0.65 eV below the conduction band. OH ion injection appears to be a potential degradation mechanism for uncoated Schottky barrier devices exposed to humid air.

ELEMENT: Research and Advanced Development

Prime Contractor and Address RCA Laboratories P. O. Box 432 Princeton, New Jersey 08540	Title Amorphous Thin Films For Solar Cell Applications
Principal Investigator Name: David Carlson Phone: (609) 452-2700, Ext. 3205	Contract No. ET-78-C-03-2219 Period of Performance September 1, 1978-August 31, 1979
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$246,035
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$246,035

Summary

The goal of this project is to develop low-cost a-Si:H solar panels with conversion efficiencies of greater than 10 percent by 1980. The approach used in this project will include the following:

- a. Theoretical modeling of charge transport properties and the nature of defect states in undoped a-Si:H.
- b. Optimization of the deposition of undoped, phosphorus doped, and boron-doped a-Si:H films.
- c. Characterization of the a-Si:H films.
- d. Optimization of Schottky barrier, MIS, and cermet/p-i-n solar cells on a-Si:H.
- e. Obtainment of contour plots of device parameters and correlate this data with the theoretical models of various a-Si:H solar cell structures.

ELEMENT: Research and Advanced Development

Prime Contractor and Address RCA Laboratories P.O. Box 432 Princeton, New Jersey 08540	Title Thin-Film Polycrystalline Silicon Solar Cells
Principal Investigator Name: B.W. Faughnan Phone: (609) 452-2700 Ext. 3170	Contract No. ET-78-C-03-1876 Period of Performance September 1, 1978-August 31, 1979
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$174,087
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$174,087

Summary

The goal of this project is to characterize and correlate the electrical and structural properties of grain boundaries in polycrystalline silicon. The approach used in this project will include the following tasks.

- a. Fabrication of solar cell structures in Wacker "SILSO" polycrystalline silicon by:
 - diffusion from POCl_3 source
 - ion implantation.
- b. Measurements of solar cell parameters.
- c. Laser scan studies to identify and isolate regions of cells with degraded photoresponse.
- d. Electrical, structural, and chemical characterization of these cell regions, e.g.:
 - minority carrier lifetime, diffusion length, trap level and density, spreading resistance
 - grain misorientations, internal strains
 - impurity concentrations by mass spectrometry and electron microprobe.
- e. Growth of bicrystals by the Czochralski technique to study effects of specific structures such as:
 - ordered dislocation arrays
 - coincident site boundaries.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rensselaer Polytechnic Institute Engineering Center Troy, New York 12181	Title Heterostructure GaAs Solar Cells
	Contract No. EG-77-S-01-4116
Principal Investigator Name: Sorab K. Ghandhi Jose M. Borrego Phone: (518) 270-6333	Period of Performance September 22, 1977-September 21, 1978
Work Location Troy, New York	Fiscal Year 1978 Funding \$70,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$70,000
Summary	

The objective of this program was to investigate the feasibility of fabricating Indium Tin Oxide-Gallium Arsenide (ITO/GaAs) heterojunctions using polycrystalline films of GaAs on low-cost metallic substrates. The approach involved conducting studies related to:

- Growth of polycrystalline films of GaAs by the metalorganic vapor growth process on molybdenum, and development of an interface layer for the ohmic contact.
- Grain enhancement procedures, such as annealing.
- Growth of ITO on the oxidized GaAs surface by r-f sputtering or CVD.
- Hall effect on the basic conduction mechanisms in poly-GaAs.
- Solar cell characterization as a function of the physical parameters of the device materials and variations in the device structure.

The following results were obtained:

- Techniques have been developed for chemical treatment of the molybdenum substrate to provide good adhesion to the films.
- Germanium layers have been grown for the interface, and annealed.
- GaAs has been grown on these layers. Grain size is 5 to 15 μm in a 10 μm thick layer. Techniques have been developed to reduce autodoping, and diodes with breakdown voltage of 35 volts have been achieved.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rensselaer Polytechnic Institute Engineering Center Troy, New York 12181	Title Heterostructure GaAs Solar Cells
Principal Investigator Name: Sorab K. Ghandhi Jose M. Borrego Phone: (518) 270-6333	Contract No. EG-77-S-01-4116 Period of Performance September 22, 1977-September 21, 1978
Work Location Troy, New York	Fiscal Year 1978 Funding \$70,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$70,000

Summary (continued)

- d. Techniques have been developed for selective anodization of the grain boundary edge. This has reduced the leakage current by five decades. Using these techniques, Au-GaAs cells have shown an efficiency of 2.59 percent ($V_{oc}=0.43$ V, $J = 11.8$ mA/cm², FF=51 percent) as compared to 0.32 percent on unpassivated substrates.
- e. Hall measurements have been made on polycrystalline GaAs films.
- f. Work on high-temperature CVD and RF sputtering of ITO has been discontinued because of damage to the interface layer. Neutral ion beam techniques are planned for this work.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rensselaer Polytechnic Institute Engineering Center Troy, New York 12181	Title Polycrystalline Thin-Film GaAs Solar Cells
Principal Investigator Name: Sorab K. Ghandhi Jose M. Borrego Phone: (518) 270-6333	Contract No. Grant No.: AER76-06168 (NSF/DOE)
	Period of Performance April 1, 1976-September 30, 1978
Work Location Troy, New York	Fiscal Year 1978 Funding \$70,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$140,000

Summary

The objective of this program was to investigate the feasibility of fabricating Tin Oxide/-Gallium Arsenide ($\text{SnO}_2\text{-GaAs}$) solar cells with both single and polycrystalline films of GaAs. The approach used in this project included the following:

- Growth of single films of GaAs by the metalorganic vapor growth process on single crystal GaAs substrates and on metallic substrates such as molybdenum or tungsten.
- Development of an interface layer to provide an ohmic contact between the GaAs and the metallic substrate.
- Grain enhancement procedures.
- Growth of the doped Tin-Oxide layer by chemical vapor deposition techniques.
- Growth of an insulating layer.
- Solar cell performance characterization.

The following results have been achieved:

- A reactor has been designed and built for the growth of GaAs. Diffusion lengths of $2.4\mu\text{m}$ have been achieved in this system.
- Techniques have been developed for electrochemically etching the SnO_2 layer.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rensselaer Polytechnic Institute Engineering Center Troy, New York 12181	Title Polycrystalline Thin-Film GaAs Solar Cells
Principal Investigator Name: Sorab K. Ghandhi Jose M. Borrego Phone: (518) 270-6333	Contract No. Grant No.: AER76-06168 (NSF/DOE)
	Period of Performance April 1, 1976-September 30, 1978
Work Location Troy, New York	Fiscal Year 1978 Funding \$70,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$140,000

Summary (continued)

- c. Techniques have been developed for eliminating photo-suppression effects at the SnO₂-GaAs interface.
- d. A new technique has been developed for determining the diffusion length in direct bandgap materials such as GaAs.
- e. Solar cells have been made with $V_{oc}=219$ mV, $J_{sc}=17.3$ mA/cm², and F.F.=0.52. Attempts to increase the V_{oc} to 580 mV have succeeded, but at the expense of reducing the J_{sc} . This problem has been traced to the high temperatures involved in the deposition of the SnO₂.
- f. Work has begun on the development of a low-temperature CVD system with r.f. assist. The growth of undoped SnO films at room temperature by this method has been only very recently achieved. Doping of these films must be done prior to cell fabrication.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rockwell International Science Center P. O. Box 1085 Thousand Oaks, California 91360	Title Development of High-Efficiency GaAs Solar Cells
Principal Investigator Name: Dr. James Harris, Sr. Phone: (805) 498-4545	Contract No. EG-77-C-03-1712
Work Location Thousand Oaks, California	Period of Performance September 19, 1977-December 1, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$998,870
	Cumulative Funding \$998,870
Summary	

The technical objective of this program is to: (1) develop potentially low-cost, thin film polycrystalline GaAs solar cells with 10 percent conversion efficiency; (2) identify the mechanisms by which grain boundaries limit cell performance; and (3) investigate fabrication techniques and solar cell designs which minimize the adverse effects of grain boundaries.

To obtain this objective the following tasks are required:

- a. Produce epitaxial large-grain polycrystal GaAs structures by liquid phase epitaxy (LPE) and molecular beam epitaxy (MBE) growth on polycrystal GaAs substrates for initial grain boundary studies and initial polycrystal solar cell fabrication and modeling.
- b. Develop molecular beam epitaxy for the growth of thin polycrystal GaAs films on carbon, aluminum, and other low-cost substrates. Investigate crystallite nucleation, coalescence, growth into continuous layers, and dopant incorporation, particularly at the substrate interface and the top surface for GaAs and GaAlAs, respectively.
- c. Develop current controlled liquid phase epitaxy for the growth of thin-film polycrystal GaAs and GaAlAs on low-cost substrates. Investigate growth conditions necessary for nucleation, growth into continuous films, and dopant incorporation.
- d. Investigate the effects of grain boundaries formed in large grain polycrystal materials. In order to simulate the eventual device structure and maintain maximum reproducibility, LPE and MBE layers will initially be grown on polycrystal GaAs substrates. Measure the grain boundary effects on majority carrier transport across the boundary and minority carrier transport both parallel to and across the boundary. Determine the effects of grain size.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rockwell International Science Center P. O. Box 1085 Thousand Oaks, California 91360	Title Development of High-Efficiency GaAs Solar Cells
Principal Investigator Name: Dr. James Harris, Sr. Phone: (805) 498-4545	Contract No. EG-77-C-03-1712
	Period of Performance September 19, 1977-December 1, 1978
Work Location Thousand Oaks, California	Fiscal Year 1978 Funding \$998,870
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$998,870

Summary (continued)

- e. Characterize, both individually and statistically, the chemical, structural, and electrical properties of grain boundaries in small-grain (2 to 10m) polycrystal materials using analytical techniques with high spatial resolution including: scanning Auger microscope, scanning electron microscope, scanning light microscope, secondary ion mass spectrometer (SIMS), cathodoluminescence, and x-ray topography.
- f. Develop a model for the effects of grain angle, grain size, and impurity segregation on the space charge region surrounding grain boundaries. Consider potential techniques for grain boundary neutralization in models.
- g. Develop processing technologies suitable for polycrystal cell fabrication. The major studies include: substrate ohmic contacts to both p- and n-type GaAs and doping at the substrate interface, junction formation by epitaxial growth, ion implantation, and MIS structures, and top side ohmic contacts of both metal grid and transparent high-conductivity oxides for both p- and n-type materials.
- h. Fabricate and investigate GaAlAs/GaAs heterojunction and MIS polycrystal solar cells.
- i. Begin developing models for the above polycrystalline solar cell structures, including grain boundary effects. Correlate with experimental results and define an optimized polycrystal cell structure and determine its maximum potential performance.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rockwell International Corporation Anaheim, California 92803	Title Thin Films of GaAs on Low-Cost Substrates
Principal Investigator Name: P. D. Dapkus R. D. Dupuis Phone: (714) 632-3634	Contract No. EY-76-C-03-1202
	Period of Performance July 5, 1976-September 5, 1978
Work Location Anaheim, California	Fiscal Year 1978 Funding \$247,059
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$473,693

Summary

The objective of this project was to conduct studies leading to a low-cost high-energy conversion-efficient, long-life photovoltaic cell using polycrystalline films of GaAs and GaAlAs. The approach involved studies conducted in the following specific areas:

- Development of the Metalorganic-hydride Chemical Vapor Deposition (MO-CVD) process for growth of good quality single crystal or polycrystalline films of GaAs and GaAlAs as selected low-cost substrate materials.
- Evaluation of the structural, electrical, and optical properties of the films.
- Formation of heteroface GaAlAs/GaAs solar cell devices and the evaluation of these device structures for their photovoltaic properties.
- Analysis and projection of future costs of large-scale quantities of GaAs solar cells by the MO-CVD process.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Rockwell International Corporation Anaheim, California 92803	Title Thin Polycrystalline Films of Indium Phosphide on Low-cost Substrates
Principal Investigator Name: P. D. Dapkus H. M. Manasevit Phone: (714) 632-3634	Contract No. EY-76-C-04-3727 E(29-2)-3727-1st 12 mos
Work Location Anaheim, California	Period of Performance September 30, 1976-March 30, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$125,000 Cumulative Funding \$353,745

Summary

The objective of this project was to conduct fundamental studies leading to a low-cost, high-energy conversion-efficient, long-life photovoltaic cell using a polycrystalline film of Indium Phosphide (InP). The approach involved conducting studies of the following:

- a. Development of the Metalorganic-hydride Chemical Vapor Deposition (MO-CVD) process for growth of good-quality single-crystal or polycrystalline films of InP on selected low-cost substrate materials.
- b. Evaluation of the structural, electrical, and optical properties of the resulting InP films.
- c. Formation of heterojunction device structures by deposition of films of other semiconductors on the InP films, and evaluation of the photovoltaic properties of these composites.
- d. Analysis and projection of future costs of large-scale quantities of photovoltaic solar cells made by the MO-CVD process.

ELEMENT: Research and Advanced Development

Prime Contractor and Address RUTGERS - The State University Electrical Engineering Department P. O. Box 909 Piscataway, New Jersey 08854	Title Silicon Schottky Photovoltaic Diodes for Solar Energy Conversion
Principal Investigator Name: Wayne A. Anderson Phone: (201) 932-3466 Presently: (716) 831-1835	Contract No. AER 73-03197 Period of Performance June 1975-May 1978
Work Location Piscataway, New Jersey	Fiscal Year 1978 Funding \$35,000
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$97,000

Summary

This project was designed to achieve a 12.5 percent efficiency on $>1 \text{ cm}^2$ single-crystal silicon using a MIS type structure. A similar procedure was then to be applied to polycrystalline silicon to obtain maximum efficiency. Studies of conduction mechanisms, surface states, antireflection coatings, fabrication details, solar cell models, and degradation mechanisms were included in this program.

A simple vacuum evaporator was utilized to deposit materials in the formation of MIS solar cells having a structure $50\text{\AA}$ -Cr, $500\text{\AA}$ -Cu, $300\text{\AA}$ -Cr, $250 \text{ \AA}$ -oxide, on a $\langle 100 \rangle$, p-type Si wafer. An SiO_2 antireflection coating was applied after deposition of the Al grid. Smaller samples were made for I-V, G-V, and C-V studies as functions of frequency and temperature. A PAR lock-in amplifier system was used for surface state studies. Degradation studies were performed by placing encapsulated cells on the roof of the building for constant exposure to the environment. Many silicon types were studied including EFG ribbon, IBM ribbon, LEP ribbon, and Wacker "Silso" polycrystal silicon. Electron-beam-deposited 20 to $30 \text{ }\mu\text{m}$ thick Si films were also deposited on metal substrates in the laboratory.

An efficiency of 12.5 percent on 2 cm^2 MIS cells was achieved using single-crystal silicon. Similar fabrication steps produced an 8.8 percent efficiency on Wacker polycrystalline silicon. Surface state data showed levels of $5 \times 10^{11}/\text{cm}^2\text{-eV}$ for single-crystal wafers, $5 \times 10^{12}/\text{cm}^2\text{-eV}$ for Wacker polycrystal silicon, and up to $1 \times 10^{13}/\text{cm}^2\text{-eV}$ for EFG ribbon. These corresponded to open-circuit voltage values of 0.60V, 0.54V, and 0.48V, respectively. Diffusion length values ranged from $80 \text{ }\mu\text{m}$ to $20 \text{ }\mu\text{m}$ depending on silicon type. A computer program was used to predict the illuminated I-V curve based on interfacial oxide thickness, recombination factors, and surface state distribution. Environmental studies showed the need for a hermetic seal to achieve 20-year operation. Rectification and photovoltaic response were observed on e-beam-deposited, $20 \text{ }\mu\text{m}$ Si films which exhibited a columnar structure from substrate to surface. Conduction mechanisms in the thin Si films were also established.

ELEMENT: Research and Advanced Development

Prime Contractor and Address. Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title Photovoltaic Mechanisms in Polycrystalline Thin-Film Solar Cells
	Contract No. ET-78-C-01-3413
Principal Investigator Name: George Storti Phone: (301) 948-0202	Period of Performance September 30, 1978-October 29, 1979
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$119,399
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$119,399

Summary

The objective of this study is the understanding of the mechanisms in thin-film polycrystalline silicon solar cells that limit the photovoltaic conversion efficiency under solar illumination conditions. The approaches to be used in this project involve the following tasks.

- a. Develop theoretical models which predict the power conversion efficiency, J_{sc} , V_{oc} , and fill factor of thin-film, polycrystalline, homojunction solar cells based on numerical computations treating the cell as a connected mesh of individual grain devices.
- b. Model performance of individual grains by adapting existing models of single-crystal solar cells to include the effects of:
 - distribution of impurities/defects within the structure
 - grain boundary geometry
 - grain boundary energy level structure
 - surface and grain boundary recombination
 - junction area
 - optical absorption vs. wavelength and doping density.
- c. Construct a fine-geometry, multi-spectral light spot scanning system to evaluate minority carrier collection efficiency as a function of wavelength, position, and depth.
- d. Develop deep-level transient spectroscopy measurements to evaluate levels within the bandgap affecting carrier lifetime and cell efficiency.
- e. Using the measurement techniques of "c" and "d," investigate the effects of grains and grain boundaries on the physical and electrical properties of the polycrystalline material.
- f. Determine the structural and compositional characteristics of the samples and correlate with the results of electrical characterization.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Southern California University Park Los Angeles, California 90007	Title Low Cost Solar Cells Based on Amorphous Silicon Electro- deposited from Organic Solvents
Principal Investigator Name: F. A. Kroger Phone: (213) 741-6224	Contract No. EY-76-S-03-0113-PA-40 Period of Performance
Work Location Los Angeles, California	Fiscal Year 1978 Funding \$54,824
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$54,824

Summary

The goal of this project is to develop the electrodeposition process to produce amorphous silicon solar cells. The approach necessary to achieve the project objectives consists of the following tasks:

- a. Select appropriate electrolytes, current densities, and deposition potentials for electrodeposition of amorphous silicon on nickel, stainless steel, oxide-coated glass, or plastic sheet covered with thin gold film.
- b. Characterize the structure, composition, and electrical properties of the silicon films.
- c. Determine the deposition conditions necessary for doping the plated silicon films.
- d. Fabricate Schottky barrier solar cells.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Southern Methodist University Dallas, Texas 75275	Title Silicon Thin Films on Metallurgical Silicon Substrates
Principal Investigator Name: Ting L. Chu Phone: (214) 692-3014	Contract No. EY-76-C-03-1285
	Period of Performance October 1, 1977-September 30, 1978
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$179,380
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$377,637

Summary

The objective of this project was to investigate silicon films on metallurgical silicon substrates in order to produce thin-film solar cells with an AM1 efficiency of 10 percent by 1979.

To achieve the project objective, five technical areas were under investigation:

- a. The purification of metallurgical silicon.
- b. The preparation of metallurgical silicon substrates by recrystallization.
- c. The deposition and characterization of silicon films on metallurgical silicon substrates.
- d. The characterization of grain boundaries and the reduction of their effects.
- e. The fabrication and evaluation of p-n junction solar cells and the optimization of their characteristics.

A simple technique consisting of extraction with aqua regia and heat treatment with phosphorus pentoxide was developed for the purification of metallurgical silicon. Substrates prepared from purified metallurgical silicon by unidirectional solidification on graphite were used for the deposition of (1) silicon films of controlled thickness and resistivity, and (2) the active region of solar cells. Potential probe measurements showed appreciable potential gradients at grain boundaries in silicon films with electrical resistivities higher than about 0.1 ohm-cm. Laser scanning measurements showed considerable reduction in photoresponse at grain boundaries in solar cells. Preliminary results indicated an increase in photoresponse at grain boundaries in solar cells by heat treatment. By using a back surface field at the base/substrate interface region, a drift field in the surface region, and the heat treatment technique, thin-film polycrystalline silicon solar cells with an AM1 efficiency of up to 9.5 percent were obtained.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Southern Methodist University Dallas, Texas 75275	Title Thin Films of Gallium Arsenide on Low-Cost Substrates
	Contract No. EY-76-C-03-1284
Principal Investigator Name: Shirley S. Chu Phone: (214) 692-3024	Period of Performance October 1, 1977-September 30, 1978
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$121,680
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$261,840

Summary

The objective of this project has been to investigate gallium arsenide films on tungsten/graphite and other low-cost substrates in order to produce thin-film solar cells with an AM1 efficiency of 6 percent or higher by August 1978.

To achieve the project objective, four technical areas have been under investigation: (1) the deposition of gallium arsenide films; (2) the characterization of the structural and electrical properties of deposited films; (3) the deposition of antireflection coatings; and (4) the fabrication, evaluation, and optimization of MOS solar cells.

Gallium arsenide films have been deposited on graphite and tungsten/graphite substrates by: (1) the reaction of gallium, hydrogen chloride, and arsine; and (2) the reaction of gallium, hydrogen chloride, and arsenic with similar results. The initial stage of deposition and the effect of adding hydrogen chloride to the reactant mixture have been investigated. Films deposited without intentional doping are n-type with a carrier concentration in the range of 10^{16} - 10^{17} cm⁻³, and a minority carrier diffusion length of 0.5 to 0.8 μ m. Titanium dioxide films have been deposited by the hydrolysis of tetraisopropyl titanate at 80° to 100°C as an antireflection coating for solar cells. Large-area (9 cm²) MOS cells of the configuration TiO₂/Au/oxide/n⁺-GaAs/n⁺/W/graphite have an AM1 efficiency of up to 6.7 percent. Preliminary investigations on the oxidation product of gallium arsenide have been carried out by Auger spectroscopy as one approach to the optimization of solar cell characteristics. A series of experiments concerning the stability of thin-film gallium arsenide solar cells has been initiated.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Sperry Univac Defense Systems Division Box 3525 St. Paul, Minnesota 55165	Title Cadmium Sulfide/Copper Ternary Heterojunction Cell Research
	Contract No. EG-77-C-03-1580
Principal Investigator Name: D.L. Fleming Phone: (612) 456-3163	Period of Performance September 30, 1977-November 30, 1978
Work Location St. Paul, Minnesota	Fiscal Year 1978 Funding \$193,535
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$193,535

Summary

The project objectives are to develop a cadmium sulfide/copper ternary heterojunction photovoltaic cell which can be reproducibly manufactured with an air mass 1 conversion efficiency of no less than 8 percent (as measured between 20°C and 30°C over cell areas of at least 4 cm²), with a maximum electrical output degradation of 5 percent over 20 years.

In order to meet these objectives the following approach is being pursued:

- a. Develop film fabrication techniques to obtain film having reproducible properties.
- b. Fabricate devices, analyze device performance, and implement changes in device structure and fabrication procedures to improve performance.
- c. Investigate cell degradation mechanisms.
- d. Determine cost effectiveness (cost/peak kWe) of present and projected cells.

Single-phased, stiochiometric, CuInSe₂ films having grain sizes too small for device interest have been fabricated using a flash evaporation system. Present work is directed toward films deposited using a dual source CuInSe₂ and Se system. Moderate-efficiency devices have been made using this system. Efforts are being directed toward improved deposition control, particularly of the selenium.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Spire Corporation Patriots Park Bedford, Massachusetts 07130	Title Development of Silicon Recrystallization and Thin-Film Solar Cell Processes
	Contract No. EG-77-C-01-4106
Principal Investigator Name: A.R. Kirkpatrick Phone: (617) 272-5202	Period of Performance September 30, 1977-September 30, 1978
Work Location Bedford, Massachusetts	Fiscal Year 1978 Funding \$190,448
Government Technical Representative and Address	Cumulative Funding \$190,448

Summary

The objective of this project was to investigate the recrystallization technique and other special processing techniques for the fabrication of thin-film solar cells with a conversion efficiency of at least 10 percent.

The approach entailed:

- a. The investigation and development of an effective method for achieving silicon film recrystallization by use of directed energy beams.
- b. The development of a specific concept for producing silicon film solar cells on glass sheets involving use of temporary deposition substrates, directed energy recrystallization, ion-implanted junctions, directed energy annealing, and electrostatic bonding transfer to glass.
- c. The investigation of the feasibility of employing ion implantation and directed energy annealing techniques to produce high-performance Gallium Arsenide (GaAs) homojunction cells.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Syracuse University Dept. of Electrical & Computer Engineering Syracuse, New York 13210	Title Heterojunction Solar Cells
Principal Investigator Name: R.L. Anderson Phone: (802) 656-3330	Contract No. NSF-AER 76-04168
Work Location Syracuse, New York	Period of Performance June 1, 1976-May 31, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$34,000
	Cumulative Funding \$99,900

Summary

The primary objectives of this program were to create a better understanding of the principles of heterojunction solar cell (HJSC) operation and to evaluate the practicality of its use for low-cost, large-scale photovoltaic energy conversion. Particular emphasis was placed on the investigation of potential degradation mechanisms. The active substrate of principal interest is silicon in both single-crystal and polycrystalline form. The window materials include In_2O_3 , SnO_2 , and alloys of these materials. To meet the described objectives, the following tasks were conducted:

- a. Operational models were developed for HJSC's in terms of material properties such that ultimate performance capabilities and limitations could be predicted.
- b. The degradation mechanisms intrinsic to HJSC's were investigated.

It was concluded that:

- a. A fundamental parameter related to the ultimate conversion efficiencies of HJSC's with n-type windows is the electron affinity difference, ΔE_c , between substrate and window.
- b. The maximum efficiency is limited to about 11 to 13 percent with In_2O_3 windows and 18 percent with SnO_2 windows. These projected efficiencies may be increased by the inclusion of a thin interfacial (I) layer between window and substrate.
- c. An interfacial SiO_2 layer spontaneously forms in these HJSC's from the reaction of the conducting oxide window with the Si. A series resistance is associated with this layer. The reaction rate is enough in the SnO_2/Si system to generate excessive series resistance and to make such cells appear impractical for prolonged use.
- d. The reaction or degradation rate can be markedly reduced by the use of mixed metal oxide windows. The $\text{SnO}_2:\text{In}_2\text{O}_3/\text{Si}$ system is markedly more stable than either the SnO_2/Si or $\text{In}_2\text{O}_3/\text{Si}$ systems.

ELEMENT: Research and Advanced Development

Prime Contractor and Address University of Washington Joint Center for Graduate Study Seattle, Washington	Title Investigation of Low-Cost Solar Cells Based on Cu ₂ O
	Contract No. AER 7520501
Principal Investigator Name: Dr. Larry C. Olsen Phone: (509) 375-3176	Period of Performance September 1, 1975-June 30, 1978
Work Location Richland, Washington	Fiscal Year 1978 Funding \$42,538
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$116,600

Summary

The objective of this project was to investigate the photovoltaic properties of solar cells based on Cu₂O, particularly with respect to their potential for low-cost photovoltaic power conversion. Cu₂O 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, p-type Cu₂O, can be grown simply by oxidizing copper.

To meet the described objective, research efforts were concentrated on the following:

- a. Fabricating and characterizing frontwall Schottky barriers and heterojunctions.
- b. Determining approaches to the depositing of thin films of ZnO and ZnS with adequate crystalline structure and conductivity.
- c. Investigating heterojunctions based on ZnO/Cu₂O and ZnS/Cu₂O structures.

Concentration profiles obtained with Auger electron spectroscopy for Cu₂O Schottky barriers show that metals with work functions below ≈4.4 eV reduce the Cu₂O surface to produce a copper-rich layer. Thus, all such cells exhibit properties similar to Cu/Cu₂O cells. ZnS/Cu₂O heterojunctions have been investigated. An open-circuit voltage of 0.8 volts was obtained with one device.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Wayne State University Detroit, Michigan 48202	Title Cuprous Oxide Photovoltaic Cells
Principal Investigator Name: Dan Trivich, Prof. of Chemistry E.Y. Wang, Prof. Elect. Engineering Phone: (313) 577-3095	Contract No. ET-78-S-02-4726
	Period of Performance January 1, 1978-July 31, 1978
Work Location Detroit, Michigan	Fiscal Year 1978 Funding \$39,500
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$39,500 DOE (+\$82,300 NSF)

Summary

The general objective of this project was to develop methods for the production of low cost photovoltaic cells based on cuprous oxide (Cu_2O). Cuprous oxide is of interest because it is easily derived from copper which is a relatively inexpensive and highly available material and in which the U.S. is self-sufficient. Schottky barrier cells, e.g., $\text{Cu}/\text{Cu}_2\text{O}$, have been developed with a conversion efficiency of 11 percent, but tests with Al and other lower work function metal contacts on Cu_2O did not increase the barrier height, V_{oc} and η , contrary to predictions. The specific objective of this 7-month project is to determine the cause for low barrier heights in Schottky barrier Cu_2O cells and to examine the possibilities for improvement by use of oxide interlayers as in $\text{Al}/\text{Al}_2\text{O}_3/\text{Cu}_2\text{O}$ structures. This is a test of the hypothesis that chemical reactions at the interface cause the degradation of the barrier height.

The cells are prepared usually by vacuum evaporation of thin metal films directly on suitably prepared and etched Cu_2O surfaces. For the cells with oxide (or other) interlayers, various deposition methods are used, e.g., evaporation of Al in an O_2 atmosphere to yield aluminum oxide. The cells are examined by measurement of the I-V characteristics in the dark and in the light, and detailed analysis of these gives the barrier heights. The composition and chemical nature of the species are determined as a function of depth by the surface analysis techniques of Auger and ESCA spectroscopy using high resolution to differentiate between various valence states.

The Auger and ESCA studies have given very important results. In brief, these verify the hypothesis that chemical reactions occur at the interface between Cu_2O and some metals or other reducing species. This is shown by the existence of $\text{Cu}(\text{O})$, copper metal, at the interface, as revealed by the Auger and ESCA results, e.g., in $\text{Al}/\text{Cu}_2\text{O}$ structures. Thus, in $\text{Al}/\text{Cu}_2\text{O}$ or similar Schottky barrier cells made with certain low work function, chemically active metals, the cells acquire a $\text{Cu}/\text{Cu}_2\text{O}$ junction by this chemical reaction, so that the barrier heights and the V_{oc} are limited to those of the $\text{Cu}/\text{Cu}_2\text{O}$ junction.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Wayne State University Detroit, Michigan 48202	Title Cuprous Oxide Photovoltaic Cells
Principal Investigator Name: Dan Trivich, Prof. of Chemistry E.Y. Wang, Prof. Elect. Engineering Phone: (313) 577-3095	Contract No. ET-78-S-02-4726
Work Location Detroit, Michigan	Period of Performance January 1, 1978-July 31, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$39,500
	Cumulative Funding \$39,500 DOE (+ \$82,300 NSF)

Summary (continued)

The oxide interlayer may serve to prevent this reaction and, further, to provide an MIS structure with additional advantages. A few results tend to support this hypothesis. However, because the present methods of depositing Al_2O_3 are inadequate to prevent the formation of $Cu(O)$ on the Cu_2O , other deposition methods will need to be investigated. Some preliminary studies have been made with interlayers of SiO_2 , Sb_2O_3 , and Si_3N_4 also.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Westinghouse Electric Corporation Research and Development Center 1310 Beulah Road Pittsburgh, Pennsylvania 15235	Title Cadmium Sulfide/Copper-Sulfide Heterojunction Cell Research
Principal Investigator Name: John R. Szedon and Stephen J. Fonash (Penn State University) Phone: (412) 256-3394	Contract No. EG-77-C-03-1577
Work Location Pittsburgh, Pennsylvania	Period of Performance September 30, 1977-December 3, 1978
Government Technical Representative and Address Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Fiscal Year 1978 Funding \$341,426
	Cumulative Funding \$341,426

Summary

The objective of this program is to conduct research for developing cadmium sulfide/copper sulfide-based thin-film solar cells capable of 10 percent AM1 cell conversion efficiency with less than 5 percent degradation in performance over a useful life of 20 years.

To meet the described objective, the following four areas are being studied: (1) control of CdS and $\text{Cd}_x\text{Zn}_{1-x}\text{S}$ composition, doping, and electrical characteristics in thin films with crystallite sizes in the 1 μm to 10 μm range; (2) wet and dry methods of Cu_2S formation for control of resistivity and lifetime; (3) solar cell structures with topographically simple heterojunctions; and (4) copper and oxygen characterization in degradation of simple cell structures.

Several methods have been developed to reveal the morphology of Cu_2S layers on CdS films. Grain boundary penetrations to depths of 5 to 10 μm and grain diameters of 1 to 5 μm have been observed. Detailed I-V measurements under illumination reveal increasing junction bucking current (but relative insensitivity of J_{sc}) as the duration of aqueous CuCl exposure is increased. High-resolution laser scanned photo-response images show enhanced collection at the grain boundaries. Laser-excited photocurrent measurements for tapered films of Cu_2S on single-crystal and thin-film CdS give electron diffusion length values of 0.1 to 0.5 μm with relatively little influence of prolonged heat treatment. A quadruple mass analyzer has been used to monitor component fluxes during thermal evaporation of (ZnCd)S films for electrical, optical, and structural evaluations. Ion surface scattering and Auger electron spectroscopy have been used to give constituent and contaminant specie profiles in cell structures on single-crystal CdS.

ELEMENT: Research and Advanced Development

Prime Contractor and Address Westinghouse Electric Corporation Research and Development Center 1310 Beulah Road Pittsburgh, Pennsylvania 15235	Title Heterostructure Single Crystal Silicon Photovoltaic Solar Cells; Type B: Metal Heterojunction Silicon Devices
Principal Investigator	Contract No. EY-76-C-03-1282
Name: John R. Szedon and Stephen J. Fonash (Penn State) Phone: (412) 256-3394	Period of Performance September 27, 1976-October 30, 1978
Work Location Pittsburgh, Pennsylvania	Fiscal Year 1978 Funding \$123,498
Government Technical Representative and Address: Solar Energy Research Institute 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$366,097

Summary

The objective of this program is to fabricate, test, evaluate, and model photovoltaic cells of the Al-SiO₂-Si variety to assess their technical and commercial practicability for power generation.

The approach involves the following three tasks: (1) prepare and characterize MIS cells on polycrystalline silicon substrates; (2) investigate means to improve the trade-off in optical transmission and sheet conductivity of thin metal films in MIS structures; and (3) determine if significant differences exist between single-crystal and polycrystalline silicon MIS cells with regard to effects of chemically enhanced cell performance.

HF vapor exposure increases V_{oc} and J_{sc} in Al-SiO₂-pSi cells. The effect is very sensitive to atmospheric water vapor. Cells so enhanced in performance gave 11 percent conversion efficiency after AR coating. Laser-scanned photoresponse has been developed as a means to image effects of inversion layer behavior and grain boundary photo-current losses. Single-crystal cells of 13 percent efficiency (polycrystalline cells, 10 percent) based on net optical area were made using thermally evaporated SiO as an AR coating and as a charged film producing an inversion layer collecting arrangement. Back illuminated MIS cells with boron-diffused back surface field regions exhibited 3X increase in J_{sc} for back illumination compared with cells having ohmic back contacts. Film morphology and/or chemical interaction with the underlying thin oxide limit the performance of n-base cells with thin Au, Ag, Pd, or Cu films.

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Low-Cost Solar Array

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ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Aerochem, Inc. P.O. Box 12 Princeton, New Jersey 08540	Title Development of Model and Computer Code for Si Reactions
	Contract No. 954862
Principal Investigator Name: Dr. R.K. Gould Phone: (609) 921-7070	Period of Performance September 21, 1977-September 21, 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$72,820
Government Technical Representative and Address Dr. Ralph Lutwack, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$72,820

Summary

The objective of this contract was the development of a model and a computer code for Si reactions. In the performance of this effort the contractor was to:

- a. Recast the analytical model of the FULLNOZ computer code to mathematically conform to the LAPP code; recode and incorporate into LAPP as an additional subroutine.
- b. Model and code particle growth process.
- c. Test the developed code using various mechanisms.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Aerochem, Inc. P.O. Box 12 Princeton, New Jersey 08540	Title Silicon Halide-Alkali Metal Flames as a Source of Solar Grade Silicon
Principal Investigator Name: Dr. William Miller Phone: (609) 921-7070	Contract No. 954777
Work Location Princeton, New Jersey	Period of Performance May 17, 1977-July 17, 1979
Government Technical Representative and Address Dr. Ralph Lutwack, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Fiscal Year 1978 Funding \$107,814
	Cumulative Funding \$207,814

Summary

The objective of this contract is the development of a process for producing Si using silicon halide-alkali metal flames. In the performance of this effort the contractor will:

- Perform thermochemical calculations on the SiCl_4/K and Na , and SiF_4/K and Na systems.
- Perform experiments using diffusion flame burners to characterize reaction.
- Develop methods for Si collection.
- Determine the Si product purity capabilities of this process.
- Perform an economic analysis of this process.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Aerochem, Inc. P.O. Box 12 Princeton, New Jersey 08540	Title Synthesis of Silane and Silicon
Principal Investigator Name: Dr. H. Calcote Phone: (609) 921-7070	Contract No. 954560 Period of Performance July 20, 1976-September 20, 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$87,000
Government Technical Representative and Address Anthony Briglio, Jr., JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$232,518

Summary

The objective of this contract was to determine the practicality of using a nonequilibrium plasma jet for the low-cost, high-volume production of silane and silicon. In the performance of this objective the contractor was to:

- a. Investigate the production of atomic hydrogen using a nonequilibrium plasma jet.
- b. Investigate the reaction of the atomic hydrogen produced by this plasma jet with a chlorosilane, such as silicon tetrochloride or trichlorosilane to produce either silane (or a lower chlorosilane) or silicon.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Aerospace Corporation P.O. Box 92957 Los Angeles, California 90009	Title Composition Measurements by Analytical Photon Catalysis
	Contract No. 955201
Principal Investigator Name: D. Sutton Phone: (213) 648-5049	Period of Performance September 12, 1978-October 12, 1979
	Fiscal Year 1978 Funding \$45,000
Work Location Los Angeles, California	Cumulative Funding \$45,000
Government Technical Representative and Address R. Rhein, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The objective of this contract is to conduct an investigation to develop the use of Analytical Photon Catalysis and to assess the applicability of this technique for making composition analysis of silicon samples.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Arco Solar, Inc. 20554 Plummer Street Chatsworth, California 91311	Title 35 kW-Block III
	Contract No. 954751
Principal Investigator Name: W. Klosterman Phone: (213) 998-0698	Period of Performance March 1977-November 1978
Work Location Chatsworth, California	Fiscal Year 1978 Funding \$556,032
Government Technical Representative and Address Al Lawson, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$556,032

Summary

The objective of this contract is to design and develop a solar array module with high reliability, while incorporating design features which will result in a lower fabrication cost than conventional modules. Emphasis will be placed on aluminum P+ back contact design, low-cost aluminum frame, 9.25 x 46 in. panels producing 20 watts in compliance with Jet Propulsion Laboratory (JPL) environmental requirements.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Theodore Barry and Associates 1151 West Sixth Street Los Angeles, California 90017	Title Lifetime Cost and Performance Modeling Effort Support
Principal Investigator Name: J. Ayers Phone: (213) 413-6080	Contract No. 955161
	Period of Performance September 17, 1978-October 17, 1978
Work Location Los Angeles, California	Fiscal Year 1978 Funding \$49,047
Government Technical Representative and Address R.G. Chamberlain, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$49,047

Summary

The objective of this contract is to critically review and critique the methodology to define the overall structure of the Lifetime Cost and Performance (LCP) model and identify inconsistencies. To meet the described objective, the following efforts are included:

- a. Critique the methodology.
- b. Assist the submodel equations formulation.
- c. Scope Phase II follow-on effort
 - Cost Account Catalog
 - financial parameters.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Theodore Barry and Associates 1151 West Sixth Street Los Angeles, California 90017	Title Phase II Industrial Engineering Study
	Contract No. 954909
Principal Investigator Name: J. Ayers Phone: (213) 413-6080	Period of Performance October 13, 1977-April 1978
Work Location Los Angeles, California	Fiscal Year 1978 Funding \$49,730
Government Technical Representative and Address R.G. Chamberlain, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$49,730

Summary

The objective of this contract was to provide additional standard data for use in the Solar Array Manufacturing Industry Costing Standards (SAMICS) to extend the hypothetical factories to include warehousing, distribution, sales, and marketing functions and to vary the factory operating schedules. To achieve this objective, the contractor was to perform the following specific tasks:

- a. Critique the model results.
- b. Augment the manufacturing process data by adding expense items to the Cost Account Catalog, including price versus quantity, inflation, and indirect requirement data; document the augmentation procedure.
- c. Provide a product distribution submodel.
- d. Provide information for a short-run cost variation capability.
- e. Provide an alternative sales and marketing submodel.

ELEMENT: Technology Development

SUB-ELEMENT: Low Cost Solar Array

Prime Contractor and Address Theodore Barry and Associates 1151 West Sixth Street Los Angeles, California 90017	Title Solar Array Manufacturing Industry Costing Standards
Principal Investigator Name: J. Ayers Phone: (213) 413-6080	Contract No. 955123 Period of Performance July 17, 1978-December 1978
Work Location Los Angeles, California	Fiscal Year 1978 Funding \$39,577
Government Technical Representative and Address R.G. Chamberlain, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$39,577

Summary

The objective of this contract is to provide additional validation of the Solar Array Manufacturing Industry Simulation, 3rd (SAMICS III) computer program. Additional areas to be covered are:

- a. Output report critique.
- b. Indirect requirements matrix conversion.
- c. Cost Account Catalog Conversion Table.
- d. Catalog and matrix data entry.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Battelle Memorial Institute Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Title Die and Container Materials
Principal Investigator Name: Dr. Dale Niesz Phone: (614) 424-6577	Contract No. 954876
	Period of Performance September 22, 1977-March 1979
Work Location Columbus, Ohio	Fiscal Year 1978 Funding \$322,000
Government Technical Representative and Address Mel Hagan, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$322,000

Summary

The objective of this contract is to conduct a study program to develop methods for processing and fabricating selected refractory materials into a form which is resistant to the corrosive action of molten silicon. This must be amenable to the production of ribbon-forming dies and containers for molten silicon. The program objective is the successful development of:

- a. A die from which high-quality silicon ribbon can be formed.
- b. A container which does not contaminate or is not contaminated by molten silicon.

ELEMENT: Technology Development

SUB-ELEMENT: Low Cost Solar Array

Prime Contractor and Address Battelle Memorial Institute Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Title Environmental Definition, Materials Evaluation, and Testing
	Contract No. 954328
Principal Investigator Name: Donald C. Carmichael Phone: (614) 424-6582	Period of Performance October 9, 1977-July 1979
Work Location Columbus, Ohio	Fiscal Year 1978 Funding \$175,000
Government Technical Representative and Address Hugh Maxwell, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$1,242,887

Summary

The objectives of this contact relate to six interrelated studies as described below:

Study 1: Review of World Experience and Properties of Materials for Encapsulation of Terrestrial Photovoltaic Arrays. The objective is to collect and analyze available data defining the state-of-the-art of encapsulation system materials and processes to provide a credible basis for defining encapsulation task materials evaluation and development efforts.

Study 2: Definition of Terrestrial Service Environments and Test Conditions for Encapsulation Materials. The objective is to characterize environmental conditions to which terrestrial solar arrays will be explored over a 20-year lifetime to aid definition of realistic test programs for encapsulation system materials.

Study 3: Evaluation of Encapsulation Methods and Materials for Low-cost Long-life Silicon Photovoltaic Arrays. The objective is to evaluate selected materials and material combinations for use in encapsulation systems on the basis of critical initial properties and characteristics, and their behavior over time in selected environments.

Study 4: Methodology for Designing Accelerated Aging Tests for Predicting Life of Photovoltaic Arrays. The objectives are: (1) to review and assess available literature and data with respect to life prediction methodology; (2) to develop a practical and credible life prediction methodology for evaluating photovoltaic arrays and components intended for a 20-year service life; and (3) to illustrate the methodology by the design of a test program for an example array encapsulation system.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Battelle Memorial Institute Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Title Environmental Definition, Materials Evaluation, and Testing
Principal Investigator Name: Donald C. Carmichael Phone: (614) 424-6582	Contract No. 954328 Period of Performance October 9, 1977-July 1979
Work Location Columbus, Ohio	Fiscal Year 1978 Funding \$175,000
Government Technical Representative and Address Hugh Maxwell, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$1,242,887

Summary (continued)

Study 5: Evaluation of Diagnostic Methods for Use in Accelerated/Abbreviated Testing. The objectives are: (1) to identify, evaluate, and recommend techniques and instruments for measuring changes in properties of materials undergoing accelerated laboratory-simulated, or natural, weathering; (2) to determine the degree to which existing instruments are satisfactory for use in the diagnosis of array degradation; and (3) to evaluate the merits of modifying existing instruments or the need for designing and building new instrumentation to meet essential diagnostic requirements.

Study 6: Continuation of Study 3. The objective is to evaluate selected materials combinations shown to be viable candidates for silicon cell encapsulation as a result of the screening evaluations performed in Study 3. The reasons for carrying out further evaluations are: (1) the need for increased statistical validity (sufficient replicate samples will be tested); and (2) the need for establishing longer term data on rates of degradation. The electrical performance of encapsulation single cells will be evaluated after exposure to high humidity, temperature cycling, and UV.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Battelle Memorial Institute Columbus Laboratories Columbus, Ohio 43201	Title Semiconductor Grade Si Process
	Contract No. 954339
Principal Investigator Name: M.F. (Pete) Browning Phone: (614) 424-7464	Period of Performance October 9, 1975-September 1979
	Fiscal Year 1978 Funding \$430,000
Work Location Columbus, Ohio	Cumulative Funding \$1,203,757
Government Technical Representative and Address Edward Cleland, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The overall objective of this contract is to establish a chemical process for producing semiconductor-grade silicon at a rate and price commensurate with the goals of the LSA Project. In this study of candidate processes, the technical feasibility of the most promising process is established on a laboratory-scale basis and small quantities (500 gm) are produced during Phase I activities. The selected candidate process is evaluated in Phase II studies for scale-up potential to a pre-production, experimental facility having a capacity of 50 metric tons per year (50 MT/Y) of semi-conductor-grade silicon. The contractor will carry out the following tasks.

Phase I

- a. Perform theoretical and experimental chemical studies of two candidate processes: (1) decomposition of silicon tetrachloride; and (2) zinc reduction of silicon tetrachloride.
- b. Perform energy and economic studies.
- c. Conduct evaluation studies for selection of candidate process.
- d. Provide a silicon sample of 500 grams from the selected process.
- e. Perform preliminary engineering studies for process scale-up potential.

Phase II

Note: The zinc reduction of silicon tetrachloride has been selected as the proposed process.

- a. Provide a data base for technological design from theoretical and experimental studies.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Battelle Memorial Institute Columbus Laboratories Columbus, Ohio 43201	Title Semiconductor Grade Si Process
	Contract No. 954339
Principal Investigator Name: M.F. (Pete) Browning Phone: (614) 424-7464	Period of Performance October 9, 1975-September 1979
Work Location Columbus, Ohio	Fiscal Year 1978 Funding \$430,000
Government Technical Representative and Address Edward Cleland, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$1,203,757

Summary (continued)

- b. Design an experimental facility having a capacity of 50 MT/Y of silicon.
- c. Perform economic analyses for a production potential of 1,000 MT/Y of silicon.

Research and Development

Obtain data for theoretical and experimental investigations, and support design, construction, and operation of scale-up process as principal functions under the extended agreement. Also included are energy and economic analyses and silicon samples.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Bechtel Corporation 50 Beale Street San Francisco, California 94119	Title Array Life-cycle Analysis
Principal Investigator Name: W.J. Stolte Phone: (415) 768-5430	Contract No. 954848
Work Location San Francisco, California	Period of Performance September 19, 1977-August 1978
Government Technical Representative and Address Paul Sutton, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Fiscal Year 1978 Funding \$99,756
	Cumulative Funding \$99,756

Summary

This contract provided detailed costing relationships in support of the life-cycle cost modeling effort undertaken by the Array Life-cycle Analysis Task within the Project Analysis and Integration Area of LSA. The cost relationships were made for five conceptual array design approaches, including three fixed array designs, one seasonally adjusted design, and one single-axis tracking design. The responsibilities of the contractor included, but were not necessarily limited to, the following tasks:

- a. Array concepts: select five conceptual array design approaches.
- b. Array conceptual designs: develop the selected five array design approaches to enable major life-cycle cost implications to be determined.
- c. Cost estimates: determine detailed cost relationships for each of the five array design approaches and module designs.
- d. Cost dependencies: perform trade-off among design features with respect to cost elements.
- e. Utility practices: contact at least five electric utilities to determine utility practices with respect to photovoltaics.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Bechtel Corporation 50 Beale Street San Francisco, California 94119	Title Requirements for Solar Array
	Contract No. 954698
Principal Investigator Name: W.J. Stolte Phone: (415) 768-5430	Period of Performance February 7, 1977-June 30, 1979
	Fiscal Year 1978 Funding \$162,028
Work Location San Francisco, California	Cumulative Funding \$162,028
Government Technical Representative and Address Paul Sutton, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

A study shall be performed to determine the optimum photovoltaic module size, configuration, and construction by determining the lowest cost module-panel structure-foundation system. The study shall also be conducted parametrically to extend the results to different loading conditions, soil conditions, and production quantities (i.e., different manufacturing techniques and degree of automation).

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Boeing Company P.O. Box 3707 Seattle, Washington 98124	Title Feasibility Study of Solar Dome Encapsulation of Photovoltaic Arrays
	Contract No. 954833
Principal Investigator Name: D.K. Zimmerman Phone: (206) 773-2988	Period of Performance August 19, 1977-August 1978
Work Location Seattle, Washington	Fiscal Year 1978 Funding \$97,919
Government Technical Representative and Address Paul Sutton, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$97,919
Summary	

A study was performed to evaluate the use of an air-supported enclosure for encapsulation of photovoltaic solar arrays. The objectives of this study were to determine and assess the potential technical and economic benefits obtained when solar photovoltaic arrays are protected by the air-supported structures. Minimum encapsulation module and minimum support structure designs will be developed and evaluated; means for minimizing the "green house" effect of the dome will be defined, and life cycle costs will be developed.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Burt, Hill, Kosar, Rittelmann Associates 400 Morgan Center Butler, Pennsylvania 16001	Title Residential Photovoltaic Module Requirements Study
	Contract No. 955149
Principal Investigator Name: Rittelmann Phone: (412) 285-4761	Period of Performance August 3, 1978-January 1979
Work Location Butler, Pennsylvania	Fiscal Year 1978 Funding \$81,015
Government Technical Representative and Address Paul Sutton 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$81,015

Summary

The contract is to provide engineering services and other necessary support to derive a preliminary residential photovoltaic module specification together with supporting rationale. It will reflect projected 1986 photovoltaic module technology and current building codes and construction practices.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address University of California, Los Angeles 405 Hilgard Avenue Los Angeles, California 90024	Title Development and Application of X-ray Defraction Technique
Principal Investigator Name: C.N.J. Wagner Phone: (303) 234-7105	Contract No. 954851 Period of Performance October 5, 1977-October 1978
Work Location Los Angeles, California	Fiscal Year 1978 Funding \$30,359
Government Technical Representative and Address Marty Leipold, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$30,359

Summary

This project involves developing methods of characterizing large-area silicon crystals supplied by JPL with X-ray defraction techniques. Specifically, the contractor is:

- a. Developing and perfecting optimum residual stress measurements of Si ribbons up to 3 in. x 40 in.
- b. Determining residual stress on Si crystals.
- c. Developing an appropriate annealing technique to remove residual stresses.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address University of California, L.A. School of Engineering and Applied Science Los Angeles, California 90024	Title Silicon Solar Cell Fabrication Technology
	Contract No. 954902
Principal Investigator Name: Prof. O. Stafsudd Phone: (213) 825-2214	Period of Performance October 5, 1977-July 1979
	Fiscal Year 1978 Funding \$35,453
Work Location Los Angeles, California	Cumulative Funding \$35,453
Government Technical Representative and Address G. Pollack, JPL 4800 Oak Grove Dr. Pasadena, California 91103	
Summary	

The contract is directed towards providing device fabrication services in support of silicon sheet evaluation. This contract will entail the following tasks:

- a. Fabricate solar cells and other appropriate test devices on the silicon samples supplied by JPL. (Processing will be defined by JPL.)
- b. Provide processing and device testing as appropriate.
- c. Maintain equipment operation logs.
- d. Provide documentation.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Case Western Reserve University 2040 Adelbert Road Cleveland, Ohio 44106	Title System Studies Basic Aging and Diffusion
	Contract No. 954738
Principal Investigator Name: Professor C.E. Rogers Phone: (216) 368-4175	Period of Performance March 21, 1977-November 1978
Work Location Cleveland, Ohio	Fiscal Year 1978 Funding \$18,750
Government Technical Representative and Address J. Moacarin, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$50,000

Summary

The objective of this study is to determine the effects of progressive degradation caused by environmental stresses on the permeability of encapsulants. Detailed goals are to:

- a. Standardize the procedures and equipment for measuring permeability, diffusion, and solubility coefficient using the well understood nitrogen gas/polyethylene and water vapor-polyethylene systems.
- b. Determine the transport behavior of polymethylmethacrylate/polyisoprene copolymer films after photo-oxidation.
- c. Determine the changes in the UV-visible spectral crystallinity, and density of the films due to photo-oxidation.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Clemson University College of Engineering Clemson, South Carolina	Title Solar Cell Reliability Test
	Contract No. 954929
Principal Investigator Name: Dr. J. Prince Dr. J. Lathrop Phone: (803) 656-3371	Period of Performance December 9, 1977-December 1978
	Fiscal Year 1978 Funding \$105,000
Work Location Clemson, South Carolina	Cumulative Funding \$105,000
Government Technical Representative and Address E. Royal, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The contract is to provide investigations of factors involved in the reliability of terrestrial solar cells and develop a specification for the accelerated stress testing of solar cells.

ELEMENT: Technology Development
SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Coors Porcelain Co. 600 Ninth Street Golden, Colorado 80401	Title Low-Cost Silicon Array Container Material
	Contract No. 954878
Principal Investigator Name: D. Wirth Phone: (303) 278-4000	Period of Performance October 6, 1977-September 1978
	Fiscal Year 1978 Funding \$105,425
Work Location Golden, Colorado	Cumulative Funding \$105,425
Government Technical Representative and Address Marty Leipold, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The objective of this contract was to develop and test low-cost mullite for potential application as a substrate and crucible material. The emphasis was on low-cost and large-volume processing methods. The development included:

- a. Geometry.
- b. Composition and microstructure.
- c. Interaction with molten silicon.
- d. Fabrication techniques.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Cornell University Ithaca, New York 14853	Title Characterization of Structural, Electrical, and Chemical Properties of Silicon
	Contract No. 954852
Principal Investigator Name: Prof. Dieteras Phone: (607) 256-4140	Period of Performance March 1978-October 1979
Work Location Ithaca, New York	Fiscal Year 1978 Funding \$90,000
Government Technical Representative and Address R. Kachare, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$90,000
Summary	

This contract is to provide the basic research efforts towards correlating the structural, electrical, and chemical properties of silicon sheet material.

The project shall:

- a. Utilize transmission Electron Microscopy (TEM) Scanning, TEM-Electron Beam Induced Current (EBIC) Techniques, and X-ray and optical techniques.
- b. Determine the electrical properties of the structural defects in silicon sheets.
- c. Investigate the effect of structural defects on the distribution of chemical impurities using ion microprobe and also conduct chemical analysis using mass spectroscopy.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Crystal Systems, Inc. 35 Congress Street P.O. Box 1057 Salem, Massachusetts 01970	Title HEM Slicing Process
Principal Investigator Name: Fred Schmid Phone: (617) 745-0088	Contract No. 954373
	Period of Performance November 20, 1975-December 1978
Work Location Salem, Massachusetts	Fiscal Year 1978 Funding \$399,832
Government Technical Representative and Address Dr. Tom Digges, JPL 4800 Oak Grove Dr. Pasadena, California 911034	Cumulative Funding \$1,035,633

Summary

The objective of this contract is to develop methods (feasibility) to produce large areas of silicon sheet material by the heat exchanger ingot casting/slicing process suitable for use as cost effective solar cells. The heat exchanger method is based on solidification from bottom to top with growth initiating from a seed with unidirectional heat flow controlled by a heat exchanger. The contractor is to demonstrate feasibility by modifying growth furnace, making experimental castings, and giving consideration to seeding, growth rate, crystallization kinetics, fluid dynamics, and heat flow. The contractor is to develop methods to prevent cracking during cooling after solidification. The contractor is to demonstrate 2.5 kg single crystal free from cracks.

The contractor is to develop multiple wire slicing (feasibility) with wire thickness of 0.0075 cm, slice thickness of 0.015 cm, and with slicing rate of 0.25 cm per minute. The contractor is to demonstrate feasibility by modifying an existing slicing machine, making experimental runs, determining methods of slicing failures, investigating and optimizing wire (substrate). The contractor is to evaluate scale-up potential with economic analysis. The contractor is to perform characterization on growth and slicing samples.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Dow Corning Corporation Midland, Michigan 48640	Title Encapsulation System
Principal Investigator Name: William Dennis Phone: (517) 496-4655	Contract No. 954995
	Period of Performance February 14, 1978-September 1979
	Fiscal Year 1978 Funding \$125,000
Work Location Midland, Michigan	Cumulative Funding \$125,000
Government Technical Representative and Address E. Cuddihy, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The contract is to develop and characterize improved silicone and silicone-based materials for encapsulation systems suitable for low-cost solar cell modules up to 48 x 48 inches in size for service in terrestrial environments for a minimum of 20 years.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Dow Corning Corporation Hemlock, Michigan 48626	Title Solar Cell Grade Si Process, ARC Furnace
Principal Investigator Name: Dr. Leon Crossman Phone: (517) 642-5201	Contract No. 944559 Period of Performance July 30, 1976-January 1979
Work Location Hemlock, Michigan	Fiscal Year 1978 Funding \$457,733
Government Technical Representative and Address Edward Cleland, JPL 4800 Oak Grove Dr. Pasadena, California	Cumulative Funding \$805,733

Summary

The objective is to determine the feasibility of an arc-furnace process for the production of silicon (Si). The process involves an electric submerged-arc furnace, which smelts higher-than-normal-purity quartzite (SiO_2) and carbon reductant, for producing an Si product and, subsequently, further refining the arc-furnace Si by using Czochralski (CS) or Bridgeman (B) unidirectional solidification techniques. In performance of the objectives, the contractor will carry out the following activities.

a. Conduct studies for selection of raw materials:

- determine the location of suitable supplies of raw materials.
- evaluate the raw material properties.
- develop chemical methods for purifying reactants.

b. Perform theoretical and experimental chemistry studies involving:

- the arc-furnace operation.
- studies of a development-size arc furnace.
- influences of reaction mixtures, furnace operating conditions, electrode characteristics, and the transfer and collection of Si.
- reaction rates, yields, mass balances of reactants, and the environmental impact.
- the refining using CS or B techniques.

c. Demonstrate the feasibility of the proposed process and supply representative Si product samples and analyses.

d. Perform preliminary engineering studies and economic analyses for a 1,000 metric ton/year Si facility.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Dow Corning Corporation Hemlock, Michigan 48626	Title Solar Cell Grade Si Process, ARC Furnace
Principal Investigator Name: Dr. Leon Crossman Phone: (517) 642-5201	Contract No. 944559
	Period of Performance July 30, 1976-January 1979
	Fiscal Year 1978 Funding \$457,733
Work Location Hemlock, Michigan	Cumulative Funding \$805,733
Government Technical Representative and Address Edward Cleland, JPL 4800 Oak Grove Dr. Pasadena, California	

Summary (continued)

The extended contract is to include:

- a. Program plan.
- b. Evaluation criteria.
- c. Carbon reductant studies.
- d. Submerged-arc furnace studies.
- e. Unidirectional solidification studies.
- f. Analyses.
- g. Process selection.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Eagle-Picher Industries, Inc. P.O. Box 1090 Miami, Oklahoma 74354	Title Die and Container Materials
Principal Investigator Name: Dr. J. Stiglich Phone: (918) 542-1801	Contract No. 954877
Work Location Miami, Oklahoma	Period of Performance September 29, 1977-March 1979
Government Technical Representative and Address Mel Hagan, JPL 4800 Oak Grove Dr. Pasadena, California	Fiscal Year 1978 Funding \$75,000
	Cumulative Funding \$75,000

Summary

The objective of this contract is to conduct a study program to develop methods for processing and fabricating selected refractory materials into a form which is resistant to the corrosive action of molten silicon and which is amenable to the production of ribbon-forming dies and containers for molten silicon. The program objective is the successful development of: (1) a die from which high-quality silicon ribbon can be formed; and (2) a container which does not contaminate or is not contaminated by molten silicon.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Endurex Corporation P.O. Box 11154 Dallas, Texas 75223	Title Solar Cell Module Ion-Plating
	Contract No. 954728
Principal Investigator Name: Brian Finegan Phone: (214) 270-2700	Period of Performance March 1977-September 1978
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$29,997
Government Technical Representative and Address Edward Cuddihy, JPL 4800 Oak Grove Dr. Pasadena, California	Cumulative Funding \$68,097
Summary	

The contractor conducted a detailed investigation and study into the feasibility of encapsulating silicon solar cells, electrical interconnects, silicon solar cell arrays by ion-plating onto the surfaces thereof, transparent barrier coatings of metal oxides, and rare-earth element oxides. The barrier coatings provided corrosion protection by having resistance to penetration and permeation by moisture, oxygen, and other harmful atmospheric agents.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address General Electric Company Valley Forge Space Center P.O. Box 8555 Philadelphia, Pennsylvania 19101	Title Development and Testing of Shingle-Type Solar Cell Modules
	Contract No. 954607
Principal Investigator Name: Neal F. Shepard Phone: (215) 962-4141	Period of Performance June 15, 1977-November 1978
Work Location Philadelphia, Pennsylvania	Fiscal Year 1978 Funding \$45,614
Government Technical Representative and Address L.E. Sanchez, JPL 4800 Oak Grove Dr., Pasadena, California	Cumulative Funding \$242,728

Summary

The objective of this contract is to design, develop, fabricate, and test silicon solar cell modules which are suitable for use in place of roofing shingles on residential or commercial buildings.

The contract goals are divided into six separate sub-tasks:

- a. Substrate evaluation and testing. In this sub-task a complete survey of materials will be made and will end with a thorough testing of all promising materials.
- b. Solar cell tray evaluation and testing. This sub-task begins with a complete survey of encapsulates and tray materials. It includes a definition of design concepts and ends with a complete evaluation of these concepts.
- c. Module inter-connections and testing. This sub-task involves a complete evaluation of inter-connect materials and the testing of these materials.
- d. Shingle module design. This sub-task involves a complete evaluation of different module designs and ends with a module design review at JPL and approval of the acceptable design.
- e. Fabrication and testing of modules. In this sub-task modules are being fabricated using the approved design. They are then being electrically and environmentally tested at General Electric and JPL.
- f. Qualification testing of modules. In this sub-task modules are being tested in accordance with an approved qualification testing procedure. The tested modules are then being shipped to JPL.
- g. Analytical model of a zero-depth solar photovoltaic concentrator.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address General Electric Company Research and Development Center P.O. Box 8 Schenectady, New York 12301	Title Floating Substrate Sheet Growth Process
Principal Investigator Name: Dr. M. Garfinkel Phone: (518) 385-4686	Contract No. 954350 Period of Performance January 6, 1977-January 1978
Work Location Schenectady, New York	Fiscal Year 1978 Funding \$38,023
Government Technical Representative and Address J. Zoutendyk, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$313,327

Summary

This contract explored basic principles and determined parameters for the floating substrate process. The investigations included:

- a. Supercooling.
- b. Crystal growth from supercooled alloy.
- c. Silicon uptake from silicones.
- d. Surface growth.

An extended contract will:

- a. Determine compatibility of candidate furnace tray materials with molten Sn-Si alloys in hydrogen atmosphere.
- b. Investigate effects of maintenance of Sn-Si melt saturation with a solid silicon source.
- c. Operate seeded growth furnace with hydrogen gas jet cooling, hydrogen purging, or other relevant procedures, using the most desirable tray materials.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Gnostic Concepts, Inc. 2710 Sand Hill Road Menlo Park, California 94025	Title Industrialization Study
	Contract No. 954899
Principal Investigator Name: John Day Phone: (415) 854-4672	Period of Performance September 26, 1977-November 1978
	Fiscal Year 1978 Funding \$151,897
Work Location Menlo Park, California	Cumulative Funding \$151,897
Government Technical Representative and Address J.W. Doane, JPL 4800 Oak Grove Dr. Pasadena, California 91103	
Summary	

The contractor is performing a study to develop a detailed understanding of the decision making process by which industrial concerns evaluate investment ventures into photo-voltaic manufacturing. The contractor is directing particular attention to financial reward, technical risk, and market risk; the manner in which these considerations could be affected by rapid technological advances, successful or unsuccessful demonstrations of production or application technologies, and alternative Government policies for industry stimulation is being examined.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Honeywell, Inc. Corporate Research Center 1071 Lyndale Avenue Bloomington, Minnesota 55429	Title Novel Growth-Dip Coating
Principal Investigator Name: P.W. Chapman Phone: (612) 887-4455	Contract No. 954356
Work Location Bloomington, Minnesota	Period of Performance October 21, 1975-January 1979
Government Technical Representative and Address M. Leipold, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Fiscal Year 1978 Funding \$400,000
	Cumulative Funding \$1,073,784

Summary

The contractor will investigate the economic feasibility of producing solar-cell quality sheet silicon by coating one surface of carbonized ceramic substrates with a thin film of silicon from melt.

Add-on contract activities continuing through January 31, 1979 entail:

- a. Operating the dip facility.
- b. Operating contractor-owned dip coating machine.
- c. Developing and characterizing substrates, as required.
- d. Developing procedures for producing carbon or silicon carbide films on ceramic substrates.
- e. Operating the continuous film coating facility.
- f. Conducting economic analysis and projecting costs.
- g. Performing characterization/tests on dip film coated samples.
- h. Fabricating, evaluating, and providing solar cells and their associated data.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Kayex Corporation Hamco Division 1000 Milstead Way Rochester, New York 14624	Title Development of Advanced Methods for Continuous CZO Si Growth
Principal Investigator Name: Dr. R. Lane Phone: (716) 235-2524	Contract No. 954888 Period of Performance September 21, 1977-March 1979
Work Location Rochester, New York	Fiscal Year 1978 Funding \$270,000
Government Technical Representative and Address Dr. Akaram Kackare, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$270,000

Summary

The objective of this contract is to develop a method of continuous Czochralski growth process capable of producing silicon sheet suitable for fabricating solar cells that would meet the technical goals of the Low-Cost Solar Array Project.

In pursuit of this objective the contractor shall:

- Modify the existing CG 2000 growth furnace owned by the contractor. (The modified furnace will include Automatic Diameter Control optical system, polysilicon feed system, dopant fixture, modification of bead chain/cable mechanism, and melt level control via weight of crystal.)
- Initiate crystal growth development, including development of polytransfer system.
- Develop an economic model of the continuous Czochralski growth process.
- Perform theoretical analysis. (Typical elements for theoretical consideration will be crystallization and seeding heat-flow fluid dynamics of molten silicon and maximum pull-rate.)
- Demonstrate growth of five crystals each of 4-inch diameter minimum and of 20 kg in weight in a continuous sequence using a common crucible. (The growth rate shall be 10 cm per hour.)

ELEMENT: Technology Development
SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Kinetic Coatings, Inc. P.O. Box 416 South Bedford Street Burlington, Massachusetts 01803	Title Phase 2 of the Array Automated Assembly Task
Principal Investigator Name: Dr. W. J. King Phone: (617) 275-6000	Contract No. 955079
	Period of Performance June 8, 1978-April 1979
Work Location Burlington, Massachusetts	Fiscal Year 1978 Funding \$97,020
Government Technical Representative and Address Robert Josephs, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$97,020

Summary

The contractor shall investigate the use of ion implantation, ion beam sputtering, and electron beam deposition techniques for a simplified process. This process may be applied to the automated manufacture of solar cells at optimum efficiency that are hermetically sealed against typical terrestrial environment.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Lamar University P.O. Box 10053 Beaumont, Texas 77710	Title Process Feasibility Study
Principal Investigator Name: Professor Carl Yaws Phone: (713) 838-8310	Contract No. 954343 Period of Performance October 1, 1975-September 23, 1978
Work Location Beaumont, Texas	Fiscal Year 1978 Funding \$70,000
Government Technical Representative and Address Dr. Ralph Lutwack, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$375,528

Summary

The primary objective of this contract was to conduct a series of economic analyses of Si process developments. In the performance of this effort, the contractor:

- a. Performed analyses of process-system properties which led to chemical and physical description of the process-system.
- b. Performed theoretical and experimental chemical engineering studies and analyses which determined the kinetic and practical yield properties of the processes. (The analyses will be used to perform assessments of optimized process-designs.)
- c. Performed economic analyses of processes capable of low-cost, high-volume production of Si and calculated the total product costs for various processes.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Lockheed Missiles & Space Company, Inc. Space Systems Division Sunnyvale, California 94088	Title Phase 2 of the Automated Array Assembly Task
Principal Investigator Name: Michael Lopez Phone: (408) 743-0466	Contract No. 954898 Period of Performance October 28, 1977-December 1978
Work Location Sunnyvale, California	Fiscal Year 1978 Funding \$70,000
Government Technical Representative and Address B.D. Gallagher, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$70,000

Summary

The objective of this contract is to develop and verify processes for making solar cells and modules from Czochralski single crystal silicon.

Emphasis will be placed on techniques for laser annealing of implanted junctions and anti-reflective coatings using spray-on tantalum pentoxide solutions.

The specific contract goals are to:

- a. Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- b. Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- c. Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- d. Define the type of verification required for each process step to demonstrate technological readiness.
- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Lockheed Missiles & Space Company, Inc. Lockheed Palo Alto Research Laboratory 3251 Hanover Street Palo Alto, California 94303	Title Spraylon Fluorocarbon Encapsulation for Silicon Solar Cell Arrays
Principal Investigator Name: Dr. Mat Mc Cargo Phone: (408) 324-5193	Contract No. 954410 Period of Performance June 30, 1977-July 1978
Work Location Palo Alto, California	Fiscal Year 1978 Funding \$219,861
Government Technical Representative and Address E. Costogno, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$293,148

Summary

The objective of this contract was to design, develop, and verify the application of a low cost fluorocarbon encapsulant system, called Spraylon, to terrestrial solar modules. This development will permit the technical and economic evaluation of this system and comparison with other candidate encapsulation systems.

In the performance of this effort, the contractor shall:

- Design and develop the application of a low-cost fluorocarbon encapsulation system.
- Fabricate modules utilizing the low-cost fluorocarbon system. Modules will be tested for compliance with the LSA environmental requirements.
- Document the processes involved in using the Spraylon system in the manufacture of solar array modules.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Materials Research, Inc. 700 South 790 East Centerville, Utah 84014	Title Quantative Analysis of Defects in Silicon
Principal Investigator Name: Dr. R. Matesh Phone: (801) 531-9600	Contract No. 954977
Work Location Centerville, Utah	Period of Performance February 28, 1978-May 1979
Government Technical Representative and Address T. Odnell, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Fiscal Year 1978 Funding \$81,300
	Cumulative Funding \$81,300

Summary

The contract provides for the development of methods characterizing silicon crystals according to grain size, dislocation density, twin boundary spacing, twin boundary density, and density of impurity precipitates. The contractor shall: (1) perform bulk impurity analyses by neutron activation analysis; and (2) perform impurity analysis by several techniques to provide spatial and depth resolution of impurities, and determination of concentration detection limits.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Materials Research, Inc. P.O. Box 225 Salt Lake City, Utah 84110	Title X-ray Analysis of Silicon Wafers
	Contract No. JR-672583
Principal Investigator Name: Dr. Ram Natesh Phone: (801) 531-9600	Period of Performance July 5, 1977-January 1979
	Fiscal Year 1978 Funding \$40,000
Work Location Salt Lake City, Utah	Cumulative Funding \$52,000
Government Technical Representative and Address Amal Salma, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The objective of this program is to study nondestructively the crystallographic structure defects in the silicon wafers deliberately doped with impurities. X-ray analysis by the lung transmission technique is performed on the silicon samples before and after the p-n junction diffusion. Quantative results of the dislocation and precipitable densities are obtained from the X-ray topographs in order to correlate the structure defect density with the solar cell performance.

Extension of the contract-work was necessary to optimize the necessary procedures and to qualify the verification of the results of each technique. Additional silicon wafers will be analyzed using the identical techniques and the quantative results will be correlated.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address MB Associates Bollinger Canyon San Ramon, California 94583	Title Array Automated Assembly Task
	Contract No. 954882
Principal Investigator Name: Lynn Foote Phone: (415) 837-7201	Period of Performance November 10, 1977-December 1978
Work Location San Ramon, California	Fiscal Year 1978 Funding \$230,027
Government Technical Representative and Address L.E. Sanchez, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$230,027

Summary

The objective of this contract is to develop a manufacturing process sequence which, when implemented on a manufacturing line, will produce silicon solar modules at a cost of 50 cents per watt by 1986, thus meeting the LSA goals.

Emphasis will be placed on: (1) a new technique for the removal of an undesirable junction by the use of a plasma etching technique instead of the more expensive wet chemistry techniques now available; and (2) molding of the panel edge. The development of this process will result in a lower cost and a potentially more reliable silicon solar cell module.

The specific contract goals are to:

- Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- Define the type of verification required for each process step to demonstrate technological readiness.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address MB Associates Bollinger Canyon San Ramon, California 94583	Title Array Automated Assembly Task
	Contract No. 954882
Principal Investigator Name: Lynn Foote Phone: (415) 837-7201	Period of Performance November 10, 1977-December 1978
Work Location San Ramon, California	Fiscal Year 1978 Funding \$230,027
Government Technical Representative and Address L.E. Sanchez, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$230,027

Summary (continued)

- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Mobil Tyco Solar Energy Corporation 16 Hickory Drive Waltham, Massachusetts 02154	Title Ribbons Growth - EFG
	Contract No. 954355
Principal Investigator Name: F.D. Wald Phone: (617) 890-0909	Period of Performance October 29, 1975-March 1979
	Fiscal Year 1978 Funding \$21,995
Work Location Waltham, Massachusetts	Cumulative Funding \$21,995
Government Technical Representative and Address Marty Leipold, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The contractor shall develop methods of producing large areas of silicon ribbon by edge-defined, film-fed growth (EFG) technique, including:

- Performance of impurity studies, stress modeling, solar cell characterization, and material characterization.
- EFG machine development, demonstration of multiple growth, improvement of quality, and automated growth development.
- Production of 7.5 x 7.5 cm cells.
- Automatic control development to reduce operation labor cost.
- Economic analysis.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Mobil Tyco Solar Energy Corporation 16 Hickory Drive Waltham, Massachusetts 02154	Title Six Solar Modules
	Contract No. 954999
Principal Investigator Name: Ron S. Scharlac Phone: (617) 890-0909	Period of Performance March 10, 1978-August 1978
	Fiscal Year 1978 Funding \$21,995
Work Location Waltham, Massachusetts	Cumulative Funding \$21,995
Government Technical Representative and Address P. Alexander, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The objective of this contract was to develop and design solar array modules which shall be capable of performing within the environmental limits.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. 5005 E. McDowell Road Phoenix, Arizona 85008	Title 50 kW - Block III
Principal Investigator Name: Bob McGinnis Phone: (602) 244-5457	Contract No. BF - 672592
	Period of Performance December 9, 1977-November 1978
	Fiscal Year 1978 Funding \$687,358
Work Location Phoenix, Arizona	Cumulative Funding \$687,358
Government Technical Representative and Address R. Greenwood, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The contract is to provide for the manufacture, test, and delivery of a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 50 kilowatts.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Laser-Zone Growth in a Ribbon to Ribbon Process
	Contract No. 954376
Principal Investigator Name: Dr. Dick Gurtler Phone: (602) 244-5661	Period of Performance February 4, 1976-June 1979
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$517,765
Government Technical Representative and Address Dr. Kris Koliwad, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$1,497,765

Summary

The objective of this contract is to demonstrate the feasibility of producing large area silicon sheet by laser-zone growth using a ribbon-to-ribbon (RTR) process. The key features of the feasibility are melt zone stability and potential for rapid growth. Considerations shall be given to ribbon throughput and crystalline quality. The RTR process shall be optimized to demonstrate the scale-up potential of the RTR process. The contractor shall design and build a new RTR growth facility to achieve the following goals:

- a. 7.5 cm width.
- b. 18 cm/min. growth speed.
- c. 12 percent solar cell efficiency.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Metallization of Large Silicon Wafers
	Contract No. 954689
Principal Investigator Name: Dr. Robert Pryor Phone: (602) 244-5601	Period of Performance August 26, 1977-October 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$262,796
Government Technical Representative and Address Dr. Robert Pryor, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$284,696

Summary

The objective of this contract is to develop and verify processes for a nickel-palladium metallization system. The development of these processes will permit the technical and economic evaluation of this metallization system compared to conventional solar cell metallization systems.

The specific contract goals are to:

- a. Define process control limits for plating nickel-palladium to silicon wafers.
- b. Perform chemistry studies of the plating system and its effects.
- c. Fabricate cells using a nickel-palladium system.
- d. Determine process costs per JPL Solar Array Module Industry Cost Standards (SAMICS).

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Phase II Automated Array
	Contract No. 954847
Principal Investigator Name: Dr. Mike Coleman Phone: (602) 244-5611	Period of Performance September 27, 1977-October 1978
	Fiscal Year 1978 Funding \$466,870
Work Location Phoenix, Arizona	Cumulative Funding \$466,870
Government Technical Representative and Address A.C. Lawson, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The objective of this contract is to design, develop, and verify the performance of solar array production process steps which represent a significant technical extrapolation from state-of-the-art production approaches. Emphasis is being placed on Chemical Vapor Deposition (CVD) of silicon nitride as a combination anti-reflecting coating, plating mask, with some benefit as a junction passivation anticipated. The development of these processes permits the technical and economic evaluation of silicon sheet material.

The specific contract goals are to:

- a. Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- b. Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- c. Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- d. Define the type of verification required for each process step to demonstrate technological readiness.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Phase II Automated Array
	Contract No. 954847
Principal Investigator Name: Dr. Mike Coleman Phone: (602) 244-5611	Period of Performance September 27, 1977-October 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$466,870
Government Technical Representative and Address A.C. Lawson, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$466,870
Summary (continued)	

- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Semiconductor Grade Si Process
Principal Investigator Name: Dr. Richard Roster Phone: (602) 244-6053	Contract No. 954442 Period of Performance February 4, 1976-November 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$405,036
Government Technical Representative and Address Edward Cleland, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$868,146

Summary

The objective of this contract is the determination of the feasibility of a cyclic chemical process for producing silicon (Si) from a polymeric silicon difluoride $(\text{SiF}_2)_x$ intermediate.

The intermediate is thermally converted into Si product and SiF_4 gas, which is recovered, purified, and recycled.

The program investigative elements require the following tasks.

a. Performing theoretical and experimental chemistry studies involving:

- the conversion of metallurgical-grade Si to semiconductor-grade Si product using SiF_4 as a transfer agent
- influences of the gaseous environments, form of Si raw material; residence time, reaction temperature, rate of cooling and then heating the $(\text{SiF}_2)_x$ polymer for disproportionation, stoichiometry and the kinetics of reactions.
- the separation and collection of Si from process streams.

b. Demonstrating the feasibility of the proposed process and supplying representative Si product samples and analyses.

c. Performing preliminary engineering studies for scale-up assessment and economic analyses for a 1,000 metric ton/yr of Si facility.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Solar Cell Modules with Parallel Oriented Interconnections
	Contract No. 954716
Principal Investigator Name: Frank Hallman Phone: (602) 962-5167	Period of Performance March 10, 1977-August 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$48,032
Government Technical Representative and Address P. Alexander, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$73,604

Summary

The contractor provided for evaluation a total of 24 R&D solar panels which are designed to meet JPL Specification 5-342-1B, "Silicon Solar Cell Module Performance, Environmental Test and Inspection Requirements." The panels reflect advanced design concepts for large production volumes of silicon solar panels and employ design features, such as a copper-Kapton cell interconnect scheme, a silicon-gel capsulant system, and a glass-front steel-back enclosure system.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Technology Assessment
	Contract No. 954363
Principal Investigator Name: Mike Coleman Phone: (602) 244-5611	Period of Performance January 30, 1976-March 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$120,057
Government Technical Representative and Address D.B. Bickler, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$837,889

Summary

The objective of this contract was to perform an assessment of the improvements in current technology that may be needed to develop within a period of no more than 10 years an industrial capability for low-cost, mass production of solar arrays and modules. This assessment effort determined the process areas to which development emphasis can be placed.

The specific contract goals were:

- a. Consideration of the various forms of silicon suitable for automatic processing of low-cost solar cells. (Such forms as ribbon, sheet, dendritic web, wafers, and other processes were analyzed.)
- b. Trade-off studies relating projected costs, electric performance, and life expectancy with overall process and assembly techniques. (These techniques may become available as a result of new technology developments in areas such as silicon sheet growth, diffusion processes, and module encapsulation.)
- c. Studies of interconnect technology for electrically joining solar cells in series and parallel, including comparative analyses of wrap-around contact cells and of front and back contact cells. (The processes for making interconnections included, but were not limited to, aluminum electroforming, metal evaporation, welding, or ultrasonic bonding.)
- d. Studies of the applicability of present state-of-the-art manufacturing technology to a fully automated manufacturing facility. (The processes for silicon material production, silicon crystal growth, solar cell manufacture, testing, and assembly of solar cells into array modules were included.)

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Motorola, Inc. Semiconductor Products Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Technology Assessment
Principal Investigator Name: Mike Coleman Phone: (602) 244-5611	Contract No. 954363 Period of Performance January 30, 1976-March 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$120,057
Government Technical Representative and Address D.B. Bickler, JPL 4800 Oak Grove Dr: Pasadena, California 91103	Cumulative Funding \$837,889

Summary (continued)

- e. Detailed cost analyses to demonstrate the capability of a conceptual design being proposed for continued development in the future.
- f. Studies of the influences of primary variables upon each process or process sequence. (Such studies examined the effects and cost consequences of variations of each primary variable upon the quality and quantity of output. Also included in these studies were the interactive effects of such variations upon each of the other primary variables.)

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address National Bureau of Standards Washington, D.C. 20234	Title Neutron Activation Analysis
Principal Investigator Name: Dr. Harry Rook Phone: (301) 921-2613	Contract No. WO-8604, A-2 Period of Performance February 1977-April 1979
Work Location Gaithersburg, Maryland	Fiscal Year 1978 Funding \$80,000
Government Technical Representative and Address Dr. Alan Yamakawa, JPL 4800 Oak Grove Drive Pasadena, California 91103	Cumulative Funding \$135,000

Summary

The objective of this contract is the development of procedures for the measurements of compositions by Neutron Activation Analysis and Spark Source Mass Spectrometry. In the performance of this effort, the contractor will:

- Conduct studies of the experimental conditions required to determine concentration of elements in a Si matrix* at concentrations in the range of 10^{13} to 10^{15} atom/cc, at least, using the neutron activation analysis and spark source spectroscopy techniques.
- Establish procedures which will provide measurements of the concentration of elements in the range of 10^{13} to 10^{15} atoms/cc, at least, in a Si matrix with an accuracy of 10 percent. The elements will be selected by NBS subject to JPL approval.
- Measure the concentration of element impurities in Si samples, which will be supplied by JPL, with an accuracy of 10 percent.
- Provide evaluations of the uses of the neutron activation analysis and spark source mass spectroscopy techniques for determining the concentration of element impurities in silicon materials.
- Maintain complete laboratory notebooks, documenting the effort performed, which will be made accessible for JPL review at the contractor's facility upon request by JPL. Copies of such laboratory notebooks will be delivered to JPL.
- Provide personnel to support Quarterly Task Integration Sessions at JPL, and one workshop, the location of which will be determined by JPL. These meetings will be of 2 days duration and require the attendance of a contract representative (Principal Investigator).

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address National Bureau of Standards Washington, D.C. 20234	Title Neutron Activation Analysis
Principal Investigator Name: Dr. Harry Rook Phone: (301) 921-2613	Contract No. WO-8604, A-2
	Period of Performance February 1977-April 1979
	Fiscal Year 1978 Funding \$80,000
Work Location Gaithersburg, Maryland	Cumulative Funding \$135,000
Government Technical Representative and Address Dr. Alan Yamakawa, JPL 4800 Oak Grove Drive Pasadena, California 91103	

Summary (continued)

*The Si matrix shall contain, but not necessarily be limited to, the following:

At concentrations $<10^{15}$ atoms/cc: Ni, Cu, Fe, Al, Zn, Cr, Mg, Mn, Sn, Mo

At concentrations $<10^{14}$ atoms/cc: V, Ti, Zn

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Northrop Corporation 3401 West Broadway Hawthorne, California 90250	Title Lifetime Measurement Analysis
Principal Investigator Name: Dr. Siegfried Othmer Phone: (213) 377-4811	Contract No. 954614
	Period of Performance December 16, 1976-August 1978
Work Location Hawthorne, California	Fiscal Year 1978 Funding \$52,080
Government Technical Representative and Address Dr. Alan Yamakawa, JPL 4800 Oak Grove Dr. Pasadena, California	Cumulative Funding \$65,100
Summary	

The objective of this contract was to perform measurements of minority-carrier recombination lifetime in bulk silicon and diffusion length in solar cells fabricated from the same material in order to assess the sensitivity of these parameters to the presence of impurities. Different techniques were used to cover the ranges of material resistivity and lifetime. Minority-carrier lifetimes were determined by using the transient photoconductivity decay (PCD) method and the steady-state photoconductivity method (SSPC). Diffusion lengths were determined on solar cells and other test structures by means of short circuit current measurements using either point-source excitation from a scanning electron microscope or uniform generation from a Co⁶⁰ gamma source or band edge light. Comparisons of diffusion length and lifetime methods were then made.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Optical Coating Laboratory, Inc. 15251 East Don Julian Road City of Industry, California 91746	Title High-Efficiency Long-Life Solar Panels
Principal Investigator Name: Ken Ling Phone: (213) 968-6581	Contract No. 954831
Work Location City of Industry, California	Period of Performance August 25, 1977-June 1978
Government Technical Representative and Address L.E. Sanchez, JPL 4800 Oak Grove Dr., Oak Grove, California 91102	Fiscal Year 1978 Funding \$76,000
	Cumulative Funding \$84,000

Summary

The objectives of this contract were to design, fabricate, and deliver high-efficiency, long-life terrestrial silicon solar panels utilizing high-efficiency solar cells and increased packing density.

In order to meet these requirements, the contractor:

- a. Designed a preliminary solar module used to determine design concepts to be used in the deliverable modules.
- b. Designed a high-efficiency silicon solar cell. The design of the cell included all specialized tooling, such as contact and antireflection coating tooling.
- c. Delivered the high-efficiency modules to JPL for electrical and environmental testing.
- d. Evaluated the cell and module processing sequence economically, and made cost projections for large-volume production runs.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Optical Coating Laboratory, Inc. 15251 East Don Julian Road City of Industry, California 91746	Title Ion-Implanted Solar Cells
	Contract No. 955118
	Period of Performance June 26, 1978-November 1978
Principal Investigator Name: P. Iles Phone: (213) 968-6581	
Work Location City of Industry, California	Fiscal Year 1978 Funding \$12,553
Government Technical Representative and Address D. Fitzgerald, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$12,553

Summary

The contract will provide for the determination of the effects of certain ion-implanted impurities on solar cell performance.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Optical Coating Laboratory, Inc. 15251 East Don Julian Road City of Industry, California 91746	Title Sawing Techniques
	Contract No. 954830
Principal Investigator Name: Henry Yoo Phone: (213) 968-6581	Period of Performance August 25, 1977-April 1978
Work Location City of Industry, California	Fiscal Year 1978 Funding \$36,702
Government Technical Representative and Address L.E. Sanchez, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$42,702

Summary

The purpose of this contract was to evaluate existing technology utilized in the sawing of 7.8-cm and 10.2-cm diameter silicon ingots. A major emphasis was placed on sawing using internal diameter (ID) blade saws.

In order to meet the goals of this contract, the contractor:

- a. Investigated all process and equipment variables associated with sawing using the multiblade slurry and the ID sawing methods.
- b. Characterized the resulting silicon slices by measuring taper, bow, thickness, variation, and roughness.
- c. Determined yields and manufacturing rates at a manufacturing level.
- d. Determined yield variations due to variations in slice thickness and sawing speeds.
- e. Prepared an economic analysis (SAMICS) based on all the evaluations completed within this contract.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Optical Coating Laboratory, Inc. 15251 East Don Julian Road City of Industry, California 91746	Title Silicon-Solar Cell Process Development
	Contract No. 955089
Principal Investigator Name: P. Iles Phone: (213) 968-6581	Period of Performance May 21, 1978-July 1979
Work Location City of Industry, California	Fiscal Year 1978 Funding \$75,000
Government Technical Representative and Address G. Pollack, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$75,000

Summary

This contract effort is to be directed towards the evaluation of the solar cell and the potential of unconventional silicon sheets of interest to the LASS Task/LSA Project.

The effort requires fabrication of a number of solar cells using standard and reproducible processes and reliable testing of them using standard measurement equipment and techniques. In addition, technologies are being developed and utilized which are appropriate and necessary for improving the efficiency of solar cells made from these silicon sheets, using a standard process as the baseline starting point.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address University of Pennsylvania 308 Moore D2 Philadelphia, Pennsylvania 19174	Title Analysis and Evaluation of Processes and Equipment
	Contract No. 954796
Principal Investigator Name: Prof. Martin Wolf Phone: (215) 243-4822	Period of Performance July 8, 1977-October 7, 1979
Work Location Philadelphia, Pennsylvania	Fiscal Year 1978 Funding \$185,630
Government Technical Representative and Address A.C. Lawson, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$214,285

Summary

The objective of this contract is to perform expert analyses and critical evaluation of processes and equipment, proposed or designed, for the high-volume production of Low-Cost Solar Array modules.

In the performance of this objective, the principal activities to be undertaken by the contractor will include:

- a. Accumulating and organizing data relative to solar cell and solar photovoltaic module fabrication processes. Such data shall include the quarterly and final technical reports prepared by JPL contractors for the LSA Project, published technical literature, and pertinent reports or other data from U.S. Government sources.
- b. Receiving and reviewing reports relative to the JPL/LSA Project.
- c. Evaluating the technical approaches taken and the quality and relevance of the data obtained in the LSA Project.
- d. Critically examining the methodology of economic evaluation being developed by the LSA Project.
- e. Developing and continually expanding a matrix, or matrices, of solar cell and of solar array module process sequences and process steps thought to be applicable to high-volume, low-cost production of solar cells or of solar array modules.
- f. Evaluating the technical interfaces between potentially sequential process steps or processes in particular process sequences.

ELEMENT: Technology Development
 SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address University of Pennsylvania 308 Moore D2 Philadelphia, Pennsylvania 19174	Title Analysis and Evaluation of Processes and Equipment
	Contract No. 954796
Principal Investigator Name: Prof. Martin Wolf Phone: (215) 243-4822	Period of Performance July 8, 1977-October 7, 1979
Work Location Philadelphia, Pennsylvania	Fiscal Year 1978 Funding \$185,630
Government Technical Representative and Address A.C. Lawson, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$214,285

Summary (continued)

- g. Critically examining available data for the purpose of verifying the projected costs of specific process steps of processes.
- h. Determining the relative costs of alternative process sequences and of the technical impediments to cost reductions of particular processes.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address RCA Corporation RCA Laboratories Princeton, New Jersey 08540	Title Development and Evaluation of Die Materials for Producing Silicon Ribbons by Inverted Ribbon Growth
Principal Investigator Name: G. Cullen Phone: (609) 452-2700	Contract No. 954901 Period of Performance September 30, 1977-December 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$192,672
Government Technical Representative and Address Tim O'Donnell, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$192,672

Summary

Development of chemically vapor-deposited die materials capable of producing good quality silicon ribbon by the Inverted Ribbon Growth (IRG) process. Emphasis is on Si_3N_4 and SiO_xN_y material deposited on various low-cost and compatible substrates. Also, IRG work will be conducted to characterize fabricated die materials.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address RCA Corporation RCA Laboratories Princeton, New Jersey 08540	Title Epitaxial Silicon Growth for Solar Cells
	Contract No. 954817
Principal Investigator Name: Dr. D. Richman Phone: (609) 452-2700	Period of Performance September 29, 1977-December 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$105,000
Government Technical Representative and Address Dr. Akaram Kachare, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$205,000

Summary

The objective of this contract is to develop and demonstrate the feasibility of an epitaxial silicon growth process on low-cost silicon substrates to produce epitaxial silicon material suitable for solar cells that would meet technical goals of the Low-Cost Solar Array Project.

In performance of this objective, the contractor is to:

- a. Develop a low-cost epitaxial growth process for the production of silicon sheet material on the substrates, including cast silicon, e.g., Wacker type and metallurgical grade silicon.
- b. Perform characterization tests, including structural, chemical, and electrical tests on the as-grown epitaxial layers.
- c. Fabricate and evaluate solar cells on diffused junction as well as on as-grown epitaxial junction.
- d. Re-evaluate and optimize the growth procedure for epitaxial silicon growth with respect to structural and chemical impurities in the epi-layer on the low-cost substrates.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address RCA Corporation RCA Laboratories Princeton, New Jersey 08540	Title Phase II of the Automated Array Assembly Task of the LSA Project
	Contract No. 954352
Principal Investigator Name: Brown Williams Phone: (609) 452-2700 Ext. 2535	Period of Performance September 30, 1977-October 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$99,998
Government Technical Representative and Address D.B. Bickler, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$1,065,914

Summary

The objective of this contract is to perform an assessment of the improvements in current technology that may be needed to develop within a period of no more than 10 years an industrial capability for low-cost, mass production of solar arrays and modules. This assessment effort will determine the process areas to which development emphasis can be placed.

The specific contract goals are:

- a. Consideration of the various forms of silicon suitable for automatic processing of low-cost solar cells. (Such forms as ribbon, sheet, dendritic web, wafers, and other processes are being analyzed.)
- b. Trade-off studies relating projected costs, electrical performance, and life expectancy with overall process and assembly techniques. (These techniques may become available as a result of new technology developments in areas such as silicon sheet growth, diffusion processes, and module encapsulation.)
- c. Studies of interconnect technology for electrically joining solar cells in series and parallel, including comparative analyses of wrap-around contact cells and of front and back contact cells. (The processes for making interconnections may include, but are not limited to, aluminum electroforming, metal evaporation, welding, or ultrasonic bonding.)
- d. Studies of the applicability of present state-of-the-art manufacturing technology to a fully automated manufacturing facility, including the processes for silicon material production and silicon cell array modules.(continued)
- e. Detailed cost analyses to demonstrate the capability of a conceptual design being proposed for continued development in the future.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address RCA Corporation RCA Laboratories Princeton, New Jersey 08540	Title Phase II of the Automated Array Assembly Task of the LSA Project
Principal Investigator Name: Brown Williams Phone: (609) 452-2700 Ext. 2535	Contract No. 954352 Period of Performance September 30, 1977-October 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$99,998
Government Technical Representative and Address D.B. Bickler, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$1,065,914

Summary (continued)

- f. Studies of the influences of primary variables upon each process or process sequence. (Such studies are examining the effects and cost consequences of variations of each primary variable upon the quality and quantity of output from a process or a process sequence as well as the interactive effects of such variations upon each of the other primary variables).

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address RCA Corporation RCA Laboratories Princeton, New Jersey 08540	Title Phase 2 of the Automated Assembly Task 4
	Contract No. 954868
Principal Investigator Name: Dr. Bob D'Aiello Phone: (609) 452-2700	Period of Performance January 12, 1977-January 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$846,910
Government Technical Representative and Address B.D. Gallagher, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$846,910

Summary

The objective of this contract was to develop and verify processes for making solar cells and modules from Czochralski single crystal silicon. Emphasis was placed on: (1) junction formation techniques which will give a comprehensive analysis of ion implantation, POCl_3 and spin on diffusion processes; (2) thick film metallization processes using both commercially available and RCA fabricated inks; (3) parallel gap welding techniques for inter-connect bonding; and (4) double glass panel design and fabrication.

The specific contract goals were to:

- Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- Define the type of verification required for each process step to demonstrate technological readiness.
- Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Rockwell International Corp. Science Center P.O. Box 1085 Thousand Oaks, California 91360	Title Materials Interface Problem Study
Principal Investigator Name: D.H. Kaelble Phone: (805) 498-4545	Contract No. 954739 Period of Performance March 23, 1977-December 1978
Work Location Thousand Oaks, California	Fiscal Year 1978 Funding \$124,225
Government Technical Representative and Address J. Moacanin, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$133,700

Summary

The objective of this contract is to study by physical/chemical methods the mechanisms in silicon solar cell encapsulant systems induced by the singular and combined effects of moisture, temperature, and UV radiation. Specific approaches are: (1) to evaluate the roles of surface energetics on degradation processes which affect interfacial stability; and (2) assess the feasibility of using ultrasonics and/or optical probes to locate debonds and map bond quality in modules.

In addition, a program is being conducted to develop Preventative Nondestructive Evaluation (PNDE) methodology for encapsulation systems for the LSA Project. This entails:

- a. Developing and validating the use of ultrasonic and optical/ellipsometric probes to nondestructively locate debonds and to map bond quality in solar cell modules.
- b. Accomplishing preliminary design and development of computer-controlled ultrasonic and optical/ellipsometric probes for in-process quality control and service-life certification. Results of this development will be employed in determining the final development of instrumentation and software. Consideration shall be given to the operating potential and limitations for LSA Project applications.
- c. Applying results of the physical/chemical study in the development of quantitative criteria for environmental durability using PNDE.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Rockwell International Corporation Electronics Division Autonetics Group 3370 Miraloma Avenue Anaheim, California 92803	Title Test Methods and Aging Mechanisms
Principal Investigator Name: Dr. John Farrar Phone: (714) 632-6308	Contract No. 954458 Period of Performance March 23, 1977-June 1978
Work Location Anaheim, California	Fiscal Year 1978 Funding \$7,246
Government Technical Representative and Address H.E. Marsh, Jr., JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$295,516

Summary

The objective of this contract was to develop a methodology for predicting the performance of solar cells in encapsulants for periods of up to 20 years. In performance of this effort, the contractor was to:

- a. Develop a universal test specimen (UTS) satisfactory for exposure to accelerated and natural weathering.
- b. Expose UTS to accelerated weathering with variations in insulation, relative humidity, and temperature.
- c. Expose UTS to natural weathering (Phoenix, Arizona and Miami, Florida).
- d. Make predictions based on mathematical modeling.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address C.T. Sah Associates 403 Pond Ridge Lane Urbana, Illinois 61801	Title Study Effect of Impurities in Silicon Materials
	Contract No. 954685
Principal Investigator Name: Dr. C.T. Sah Phone: (217) 328-1678	Period of Performance February 9, 1977-November 1979
	Fiscal Year 1978 Funding \$94,000
Work Location Urbana, Illinois	Cumulative Funding \$140,158
Government Technical Representative and Address Dr. Alan Yamakawa, JPL 4800 Oak Grove Dr., Pasadena, California 91103	

Summary

This project will study the effects of impurities on Si materials and on performance of solar cells. In the performance of this effort the contractor will:

- a. Perform theoretical and experimental studies of the effects of impurities on impurity-related energy levels, densities of these levels, and the carrier capture probabilities.
- b. Develop a model to be used in predicting the effects of impurities on solar cells.
- c. Perform theoretical analyses of the effects of specific impurities and processes on the properties of Si materials and on the performance characteristics of solar cells.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address J.C. Schumacher Co. Oceanside, California 92054	Title High-Velocity Continuous-Flow Reactor
	Contract No. 954914
Principal Investigator Name: Dr. John Schumacher Phone: (714) 433-1663	Period of Performance October 24, 1977-November 1978
	Fiscal Year 1978 Funding \$69,139
Work Location Oceanside, California	Cumulative Funding \$139,139
Government Technical Representative and Address Edward Cleland, JPL 4800 Oak Grove Dr., Pasadena, California 91103	

Summary

The objective of this contract is to conduct the initial phase of a program for determining the technical feasibility of a high-velocity, gaseous-reaction process for the hydrogen reduction of bromosilanes utilizing a continuous-flow reactor in which silicon (Si) particles are continuously introduced. The particles act as deposition substrates and are mixed with and conveyed by high-velocity gaseous reactants through a reaction zone; they terminate in a continuous discharge of Si product suitable for use in solar cells meeting the goals of the LSA Project.

In performance of the Phase I objectives, the contractor will carry out the following tasks.

- a. Perform theoretical and experimental chemistry studies involving:
 - the hydrogen reduction of bromosilates, particularly tribromo- and tetrabromo-silane
 - influences of the gaseous environment, stoichiometry, temperature residence time, Si particle size, rates of heating and cooling, and the kinetics of reactions
 - the separation and collection of Si product from the process stream.
- b. Design and construct unique experimental apparatus.
- c. Assess the environmental impact of experiments.
- d. Demonstrate the feasibility of the proposed chemical process and supply representative Si product samples with analyses.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Sensor Technology 21012 Lassen Avenue Chatsworth, California 91311	Title 5 kW - Block III
	Contract No. BF - 681296
Principal Investigator Name: Erwin Rubin Phone: (213) 882-4100	Period of Performance March 23, 1978-July 1978
Work Location Chatsworth, California	Fiscal Year 1978 Funding \$84,265
Government Technical Representative and Address R. Greenwood, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$84,265

Summary

The purpose of this contract was to manufacture, test, and deliver a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 5 kilowatts.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Sensor Technology, Inc. 21012 Lassen Avenue Chatsworth, California 91311	Title 40 kW - Block III
	Contract No. BF - 672593
Principal Investigator Name: Erwin Rubin Phone: (213) 882-4100	Period of Performance January 20, 1978-December 1978
Work Location Chatsworth, California	Fiscal Year 1978 Funding \$643,907
Government Technical Representative and Address R. Greenwood, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$643,907

Summary

The contract provides for the manufacture, test, and delivery of a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 40 kilowatts. This project also includes determining the Nominal Average Power (NAP) during the period of performance of the power output of each module at rated voltage, 60°C cell temperature, AMI, and 100 mW per square centimeter. This information is then being tabulated.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Sensor Technology, Inc. 21012 Lassen Avenue Chatsworth, California 91311	Title High-Efficiency Panels
	Contract No. 954605
Principal Investigator Name: Sanjeev Chitree Phone: (213) 882-4100	Period of Performance January 12, 1977-January 1978
Work Location Chatsworth, California	Fiscal Year 1978 Funding \$108,001
Government Technical Representative and Address B.D. Gallagher, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$218,901

Summary

The objective of this contract was to develop and verify volume processes for making solar modules from single-crystal Czochralski silicon. Emphasis was placed on the development of: (1) POCl_3 diffusion process; (2) laser scribing; (3) a volume texturizing process; and (4) a spin-on antireflective coating.

The specific contract goals were to:

- a. Define and verify a POCl_3 diffusion process capable of a through-put of 400 wafers per hour utilizing a 90mm wafer.
- b. Define and verify a laser scribing process capable of forming hexagonal cells at a scribing rate of 20 cm/sec.
- c. Define and verify a cost-effective volume texturing process.
- d. Define and verify a cost-effective spin-on antireflective coating process.
- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Deliver three modules of 10 percent or greater efficiency and three modules of 13 percent or greater efficiency.
- g. Provide Format A inputs for SAMICS, detailed process specifications, and process procedures.

ELEMENT: Technology Development
SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Sensor Technology 21012 Lassen Avenue Chatsworth, California 91311	Title Phase II of the Array Automated Assembly Task
	Contract No. 954865
Principal Investigator Name: Paul Dennis Phone: (213) 882-4100	Period of Performance September 20, 1977-October 1978
	Fiscal Year 1978 Funding \$394,890
Work Location Chatsworth, California	Cumulative Funding \$394,890
Government Technical Representative and Address P. Alexander, Jr., JPL 4800 Oak Grove Dr., Pasadena, California 91103	

Summary

The objective of this contract is to design, develop, and verify the performance of solar array production process steps which represent a significant technical extrapolation from state-of-the-art production approaches. Emphasis is being placed on the process development of simultaneous application of N and P+ layers and laser-scribing center-cell holes and cell edges. The development of these processes will permit the technical and economic evaluation to determine future potential of the processes in the cost and manufacture of solar cells and arrays.

The specific contract goals are to:

- Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe (1) the materials, supplies, and equipment utilized in each process step and (2) economic readiness to realize the project goals.
- Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- Define the type of verification required for each process step to demonstrate technological readiness.
- Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Siltec Corporation 3717 Haven Avenue Menlo Park, California 94025	Title Development of Advanced Methods for Continuous CZO Growth
	Contract No. 954886
Principal Investigator Name: Anthony Bonova Phone: (415) 365-8000	Period of Performance September 1977-May 1979
Work Location Menlo Park, California	Fiscal Year 1978 Funding \$239,000
Government Technical Representative and Address Dr. J.K. Liu, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$239,000

Summary

The objective of this project is to develop methods of demonstrating continuous Czochralski growth process capable of producing silicon suitable for use as low-cost solar cells. The goals of this program are:

- Continuous growth of 100 kg of single crystal silicon from one crucible.
- Resistivity of 1 to 3 ohm cm, p-type, throughout material.
- Dislocation density $<10^4/\text{cm}^2$.
- Growth rate ≥ 10 cm/hr for 10-cm diameter ingot.
- After growth yield >80 percent.

Work will include design, assembly, and test of a prototype crystal growing furnace capable of continuous liquid feed from one crucible to another while concurrently growing Czochralski crystals.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solar Power Corporation 5 Executive Park Drive N. Billerica, Massachusetts 01862	Title 50 kW - Block III
	Contract No. BF - 672594
Principal Investigator Name: William Kurth Phone: (617) 667-8376	Period of Performance December 15, 1977-August 1978
Work Location N. Billerica, Massachusetts	Fiscal Year 1978 Funding \$816,009
Government Technical Representative and Address M. Smokler, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$816,009

Summary

The contract was to provide solar cell modules equating to a total integrated power capacity of 50 kW. The nominal average power output of a solar cell module is 28.6 watts.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title Array Automated Assembly Task for LSA Project
	Contract No. 954854
Principal Investigator Name: Dr. Manfred Wihl Phone: (301) 948-0202	Period of Performance September 27, 1977-January 1978
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$392,171
Government Technical Representative and Address D.W. Boyd, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$392,171

Summary

The objective of this contract was to develop and specify a solar cell module process sequence which, when automated, would have the potential of mass producing silicon solar array modules encapsulated for protection against the Earth's environment. Emphasis was placed on the development of flame-sprayed conductors on a glass substrate, cell grinding, and spray aluminum P+ backs on circular cells. The process sequence was critically analyzed for cost effectiveness, quality throughput, and reproducibility of product.

The principal activities and avenues of inquiry to be undertaken in the development of the process sequence was documented in (1) a Process Development Plan and (2) a Program Plan, both to be approved by JPL prior to implementation.

The specific contract goals were to:

- a. Perform detailed technical and cost analyses for an overall process sequence to convert silicon solar cells into solar array modules.
- b. Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics to those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step including the critical parameters.
- c. Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title Array Automated Assembly Task for LSA Project
	Contract No. 954854
Principal Investigator Name: Dr. Manfred Wihl Phone: (301) 948-0202	Period of Performance September 27, 1977-January 1978
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$392,171
Government Technical Representative and Address D.W. Boyd, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$392,171

Summary (continued)

- d. Define the type of verification required for each process step to demonstrate technological readiness.
- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Provide input data for JPL Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title 5 kW - Block III
	Contract No. BF - 681928
Principal Investigator Name: Ramon Dominguez Phone: (301) 948-0202	Period of Performance April 5, 1978-August 1978
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$100,452
Government Technical Representative and Address M. Smokler, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$100,452

Summary

The contract provided for the manufacture, test, and delivery of a sufficient number of silicon solar cell modules to provide a total integrated power capacity of 5 kilowatts.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title High-Density Silicon Solar Panels
	Contract No. 954822
Principal Investigator Name: Dr. Manfred Wihl Phone: (301) 948-0202	Period of Performance August 15, 1977-April 1978
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$53,118
Government Technical Representative and Address B.D. Gallagher, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$64,500

Summary

The objective of this contract was to develop and verify processes for making solar modules utilizing 5 cm x 5 cm square cells.

The specific contract goals were to:

- Perform detailed technical and cost analyses for an overall module assembly process sequence to convert silicon solar cells into solar array modules.
- Deliver 12 solar modules with a module efficiency of 13 percent or greater, utilizing 14 percent efficient or greater cells.
- Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.
- Provide cost estimations for production volumes of 5, 25, and 50 kW manufactured arrays.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title Solar Breeding Feasibility
Principal Investigator Name: Dr. Manfred Wihl Phone: (301) 948-0202	Contract No. 954606 Period of Performance December 20, 1976-December 20, 1977
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$28,765
Government Technical Representative and Address Robert Josephs, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$168,634

Summary

The objective of this contract was to explore the feasibility of manufacturing photovoltaic solar array modules with electrical energy generated from photovoltaic devices. A computer model was developed describing a facility of this type. The model features capability to address and analyze many different processes and plant management plans. A feasibility study for manufacturing quality solar cells from polycrystalline wafers having less than semiconductor grade purity levels was also conducted.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title 30 kW - Block III
Principal Investigator Name: Ramon Dominguez Phone: (301) 948-0202	Contract No. BF - 672596
	Period of Performance January 20, 1978-December 1978
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$598,110
Government Technical Representative and Address M. Smokler, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$598,110
Summary	

The contract is to provide for the manufacture, test, and delivery of silicon solar cell modules to provide a total integrated power capacity of 30 kilowatts.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title Wafer Thickness Evaluation
	Contract No. 955077
	Period of Performance May 12, 1978-January 1979
Principal Investigator Name: Dr. Manfred Wihl Phone: (301) 948-0202	
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$61,210
Government Technical Representative and Address D. Boyd, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$61,210

Summary

The contract is to provide expert analysis and critical evaluation of the technical feasibility and effective cost of various wafer thicknesses for the manufacture of solar cells.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Spectrolab, Inc. 12500 Gladstone Avenue Sylmar, California 91342	Title Automated Array Assembly Task
	Contract No. 954853
Principal Investigator Name: Dr. William Taylor Phone: (213) 365-4611	Period of Performance September 30, 1977-October 1978
	Fiscal Year 1978 Funding \$705,734
Work Location Sylmar, California	Cumulative Funding \$705,734
Government Technical Representative and Address D.W. Boyd, JPL 4800 Oak Grove Dr., Pasadena, California 91103	

Summary

The objective of this contract is to develop and specify a solar cell module process sequence which emphasizes thick film metallization and wrap-around contacts over thick film insulation on solar cells. The process sequence, when automated, would have the potential of mass producing silicon solar cell array modules encapsulated for protection against the Earth's environment. This sequence is being critically analyzed for cost effectiveness, quality throughput, and reproducibility of the product.

The principal activities and avenues of inquiry to be undertaken in the development of the process sequence shall be documented in (1) a Process Development Plan and (2) a Program Plan, both subject to JPL approval prior to implementation.

The specific contract goals are as follows:

- Perform detailed technical and cost analyses for an overall process sequence to convert silicon solar cells into solar array modules.
- Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics to those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project's goals.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Spectrolab, Inc. 12500 Gladstone Avenue Sylmar, California 91342	Title Automated Array Assembly Task
	Contract No. 954853
Principal Investigator Name: Dr. William Taylor Phone: (213) 365-4611	Period of Performance September 30, 1977-October 1978
	Fiscal Year 1978 Funding \$705,734
Work Location Sylmar, California	Cumulative Funding \$705,734
Government Technical Representative and Address D.W. Boyd, JPL 4800 Oak Grove Dr., Pasadena, California 91103	
Summary (continued)	

- d. Define the type of verification required for each process step to demonstrate technological readiness.
- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Spectrolab, Inc. 12500 Gladstone Avenue Sylmar, California 91342	Title Solar Modules 40 kW - Block II
Principal Investigator Name: Tom Festa Phone: (213) 365-4611	Contract No. 954587
Work Location Sylmar, California	Period of Performance June 29, 1976-February 1978
Government Technical Representative and Address R.F. Greenwood, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Fiscal Year 1978 Funding Decrease in task description & dollars Cumulative Funding \$485,847

Summary

This contract, for the production of 40 kW of solar cell modules was a portion of the Block II (123 kW) procurement. This procurement action served three main functions:

- a. To assess the current state-of-the-art for module production, price, and design features.
- b. To stimulate production capacity for solar cell modules.
- c. To provide modules for use in the photovoltaic test and application projects.

These modules were designed and built in accordance with the requirements of JPL Document 5-343-1C, "Silicon Solar Cell Modules Performance, Environmental Test and Inspection Requirements," which specifies certain standards of acceptability in these areas. This contract was one of four awarded in open competition among prospective manufacturers.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Spire Corporation Patriots Park Bedford, Massachusetts 01730	Title Development and Test Encapsulation Materials for LSA
Principal Investigator Name: Allen Kirkpatrick Phone: (617) 275-6000	Contract No. 954521
Work Location Bedford, Massachusetts	Period of Performance May 7, 1976-February 1979
Government Technical Representative and Address Robert Holpz, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Fiscal Year 1978 Funding \$240,000
	Cumulative Funding \$674,648

Summary

The objective of this contract is to design, develop, and test equipment and processes to determine the feasibility of protecting solar cells by integral glass encapsulation using a process of electro-static bonding of silicon solar cells between two plates of borosilicate glass.

Detailed objectives include the following:

- a. Review state-of-the-art experience and progress in integral glass cover technologies.
- b. Evaluate various glasses and metals to determine their suitability for electrostatic bonding.
- c. Determine optimum conditions of temperature, pressure, time, and current flow for satisfactory electrostatic bonding of solar cells to glass.
- d. Design and manufacture various solar cell modules for test purposes in order to verify the suitability of the process to meet project objectives.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Spire Corporation Patriots Park P.O. Box D Bedford, Massachusetts 01730	Title Development of Pulsed Process for the Manufacture of Solar Cells
Principal Investigator Name: Allen Kirkpatrick Phone: (617) 275-6000	Contract No. 954786
	Period of Performance September 16, 1978-October 1978
Work Location Bedford, Massachusetts	Fiscal Year 1978 Funding \$949,812
Government Technical Representative and Address R.H. Josephs, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$949,812

Summary

The objective of this program is to develop ion implantation and associated pulsed-energy processes for low-cost manufacturing of solar cells. Accommodation to high volume automation is the prime value of the processes, with capability for fine micro-processor control, high process reproducibility, and high production yield. Cells are being manufactured automatically in a vacuum at room temperature, with a no-forming gas environment and with only dry processes (no acids or solvents). A continuous line is used without batch or rework processing. The only consumable materials used are those that form part of the cell. The technique places little constraint upon the configuration of the input solar cell base material or upon that of the completed cell.

Key elements in this program include:

- a. Detailed investigation of the effects of pulsed energy processes upon silicon materials and their computer characterization.
- b. Installation of the most sophisticated available high current solar cell ion implanter.
- c. Detailed process descriptions of optimum solar cell ion implanted junction manufacturing techniques.
- d. Investigation of optimum pulsed energy ion implant anneal methods.
- e. Detailed comparison of solar cells with junctions formed by diffusion and by ion implantation processes.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Spire Corporation Patriots Park P.O. Box D Bedford, Massachusetts 01730	Title Development of Pulsed Process for the Manufacture of Solar Cells
	Contract No. 954786
Principal Investigator Name: Allen Kirkpatrick Phone: (617) 275-6000	Period of Performance September 16, 1978-October 1978
	Fiscal Year 1978 Funding \$040,812
Work Location Bedford, Massachusetts	Cumulative Funding \$949,812
Government Technical Representative and Address R.H. Josephs, JPL 4800 Oak Grove Dr., Pasadena, California 91103	

Summary (continued)

- f. Design specifications for a dedicated solar cell ion implanter system with a production capacity at least 25 times that of contemporary units, and which can meet the 1986 LSA Program production goals.
- g. Manufacture of polycrystalline solar cells with pulsed energy techniques.
- h. Detailed manufacturing process descriptions and procedures that provide economic analyses of the processes.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Springborn Laboratories Wafer Street - Hazardville Enfield, Connecticut 06082	Title Encapsulation - Test Methods and Materials Properties Evaluation
Principal Investigator Name: Dr. Bernard Baum Phone: (203) 749-8371	Contract No. 954527 Period of Performance May 12, 1976-August 1980
Work Location Enfield, Connecticut	Fiscal Year 1978 Funding \$90,000
Government Technical Representative and Address Edward Cuddily, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$375,480

Summary

The objective of this contract is to carry out the necessary studies, analyses, testing, formulation development, and modification of materials as necessary in order to recommend materials, processes, and system design features for low-cost (approximately 23¢/ft²) automated encapsulation of solar cell modules. The encapsulation system must withstand weathering in the sense that it must provide the necessary transparency, outdoor protection, and structural support to assure electrical functionality of the module for at least 20 years. The specific goals are to: (1) review test standards and specifications; (2) test and evaluate properties and processes; and (3) perform parametric testing (accelerated aging) of as-received materials and upgraded materials.

This project tasks entail:

- a. Expanding and refining the list of encapsulant materials for each construction element of an encapsulation system and identifying those modification approaches which would best meet the LSA performance and cost goals.
- b. Surveying and investigating acrylic materials for each at the construction elements.
- c. Fabricating functional, fully encapsulated solar cell test units.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Stanford Research Institute Menlo Park, California	Title Duplex Vapor Electrochemical Method for Silicon Production
Principal Investigator Name: Dr. Leonard Nanis Phone: (415) 326-6200	Contract No. 954471 Period of Performance February 24, 1976-October 1978
Work Location Menlo Park, California	Fiscal Year 1978 Funding \$153,841
Government Technical Representative and Address Dr. Ralph Lutwack, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$420,033

Summary

This project is aimed at developing a process for producing SiF_4 by reducing SiF_4 with Na and using $\text{SiF}_4/\text{SiF}_2$ transport reaction for purification. In the performance of this effort the contractor is to:

- Develop a process for producing SiF_4 from the H_2SiF_6 component of byproducts of the fertilizer industry.
- Develop a process for reducing SiF_4 with Na.
- Develop a process for the purification of Si produced by the SiF_4/Na reaction.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Texas Instruments P.O. Box 5012 Dallas, Texas 75222	Title Array Automated Assembly Task
	Contract No. 954405
Principal Investigator Name: Dr. Barney Carbajal Phone: (214) 238-3056	Period of Performance February 2, 1976-December 1977
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$1,905
Government Technical Representative and Address Don Bickler, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$864,709

Summary

The specific goals of this contract were:

- a. Consideration of the various forms of silicon suitable for automatic processing of low-cost solar cells.
- b. Trade-off studies relating projected costs, electrical performance, and life expectancy.
- c. Studies of interconnect technology for electrically joining solar cells in series and parallel.
- d. Studies of applicability of present state-of-the-art manufacturing technology to a fully automated manufacturing facility.
- e. Detailed cost analyses.
- f. Studies of the influence of primary variables upon each process or process sequence.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Texas Instruments, Inc. P.O. Box 5012 Dallas, Texas 75222	Title Closed-Cycle Reactor Process for Producing Silicon
	Contract No. 955006
Principal Investigator Name: R. Roques Phone: (214) 238-4766	Period of Performance August 10, 1978-August 1979
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$120,000
Government Technical Representative and Address H. Levin, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$120,000

Summary

This contract is to provide the technical feasibility of a closed-cycle process for producing Si suitable for fabricating solar cells. The contract shall be directed to investigations and the assessment of the production of silicon by thermal decomposition of 100 percent SiHCl_3 in a rotary chamber reactor and the generation of SiHCl_3 by reaction with metallurgical grade silicon.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Texas Instruments Incorporated P.O. Box 5012 Dallas, Texas 75222	Title Development of Advanced Methods for Continuous CZO Growth of Si
Principal Investigator Name: Dr. Sam Rea Phone: (214) 238-2334	Contract No. 954887
	Period of Performance September 23, 1977-May 1979
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$612,460
Government Technical Representative and Address Dr. Krishna Koliwad, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$612,460

Summary

The objective of this contract is to demonstrate the Czochralski growth of 100 kg silicon single crystal ingot of 10-cm diameter utilizing one common crucible by continuous melt replenishment. The contractor proposes to design and build a Czochralski crystal growth machine capable of melt replenishment by liquid feed.

The key features of the contract are:

- a. The design, construction, and operation of melt feed.
- b. A definition of process variables for continuous CZO growth.
- c. A growth demonstration.
- d. A projected sheet cost analysis.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Texas Instruments, Inc. P.O. Box 5012 Dallas, Texas 75222	Title Development of Automated Array Processes
	Contract No. 954881
Principal Investigator Name: Dr. Barney Carbajal Phone: (214) 238-3056	Period of Performance September 30, 1977-October 30, 1978
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$612,460
Government Technical Representative and Address A.C. Lawson, JPL 4800 Oak Grove Dr., Pasadena, California 91103	Cumulative Funding \$612,460

Summary

The objective of this contract is to design, develop, and verify the performance of solar array production process steps which represent a significant technical extrapolation from state-of-the-art production processes. Emphasis is placed on process development utilizing polymer dopants and process development of proximity texturing. These processes are directed toward use in a new high-efficiency tandem-junction cell design, and will be costed and evaluated accordingly.

The specific contract goals are to:

- Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- Define the type of verification required for each process step to demonstrate technological readiness.
- Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Texas Instruments, Inc. Dallas, Texas 75222	Title Development of Tandem-Junction Cell
Principal Investigator Name: Dr. Barney Carbajal Phone: (214) 238-3056	Contract No. 954881 Period of Performance October 1978-January 30, 1979
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$612,460
Government Technical Representative and Address A. Lawson, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$612,460

Summary

This contract is to provide a modified Program Plan and a modified Process Development Plan to further develop the tandem-junction cell to produce 2 cm x 2 cm cells with an AM1 efficiency of 16 to 17 percent.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Tylan Corporation 19220 S. Normandie Av. Torrance, California 90502	Title Vitregraph Coating on Mullite
	Contract No. 954896
Principal Investigator Name: Dr. Ron Rossi Phone: (213) 532-3420	Period of Performance December 13, 1977-November 1978
Work Location Torrance, California	Fiscal Year 1978 Funding \$42,300
Government Technical Representative and Address M. Leipold, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$42,300

Summary

The contract is to develop a series of Vitregraph coatings on special substrates and evaluate the nature and geometry of these coatings. The contractor is to explore the future cost of producing coatings of these types on areas of five million square meters of material per year.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Union Carbide Corporation Chemicals and Plastics River Road Bound Brook, New Jersey 08805	Title Semiconductor Grade Si Process - Silane/Silicon
Principal Investigator Name: J. Lorenz Phone: (212) 551-2863	Contract No. 954334 Period of Performance October 6, 1975-March 1979
Work Location Bound Brook, New Jersey	Fiscal Year 1978 Funding \$851,621
Government Technical Representative and Address Dr. George Hsu, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$2,385,000

Summary

The objective of this contract is to develop a process for producing Si by incorporating a process for producing silane (SiH_4) and then a process for converting SiH_4 into Si. In the performance of this effort the contractor will:

- Develop an integrated SiH_4 process which includes redistribution reactors for converting chlorosilanes into SiH_4 , the recycling of SiH_4 by the hydrogenation to SiHCl_3 , and appropriate distillation and purification units.
- Develop an integrated process for transforming SiH_4 into Si usable for subsequent sheet processing. Free space reactor, fluidized bed reactor, and densification technologies will be investigated.
- Design an overall integrated process for the conversion of metallurgical grade Si to solar cell grade Si incorporating the SiH_4 and SiHCl_3 - conversion processes.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Varian Associates, Inc. Lexington Vacuum Division 121 Hartwell Avenue Lexington, Massachusetts	Title Development of Advanced Methods for CZO Growth
	Contract No. 954884
Principal Investigator Name: Dr. Bob Wolfson Phone: (617) 861-7200	Period of Performance September 21, 1977-May 1979
Work Location Lexington, Massachusetts	Fiscal Year 1978 Funding \$125,000
Government Technical Representative and Address Dr. Thomas G. Digges, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$315,000

Summary

The objective of this contract is to develop a method of continuous Czochralski growth capable of producing silicon sheet suitable for fabricating solar cells that would meet the technical and cost goals of the Low-Cost Solar Array Project. In performance of this objective the contractor shall:

- a. Modify an existing Varian furnace to be able to continuously feed solid silicon into the crucible. (The contractor shall also make a conceptual design for liquid silicon feed.)
- b. Initiate crystal growth development, including development of polytransfer system.
- c. Develop an economic model for the continuous Czochralski growth process.
- d. Perform theoretical analysis. (Typical elements for theoretical consideration will be crystallization and seeding, heat flow, fluid dynamics of molten silicon, and maximum pull rate.)
- e. Demonstrate growth of five crystals each of 4-inch minimum diameter and of 20 kg in weight in a continuous sequence using a common crucible. (Growth rate shall be 10 cm per hour.)
- f. The contractor shall develop sensors, hardware, and automation, as required, to increase the after-grind yield of the growth process from 65 percent to 80 percent.
- g. Demonstrate the feasibility of 100-kg growth cycles.
- h. Demonstrate batch recharging with solid silicon.
- i. Design and develop a prototype puller.
- j. Investigate and evaluate energy utilization.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Varian Associates, Inc. Lexington Vacuum Division Lexington, Massachusetts 02173	Title Slicing of Si Ingots for LASS of LSA
	Contract No. 954374
Principal Investigator Name: Scott Holden Phone: (617) 861-7200	Period of Performance January 9, 1976-October 1979
	Fiscal Year 1978 Funding \$375,132
Work Location Lexington, Massachusetts	Cumulative Funding \$800,132
Government Technical Representative and Address Dr. J.K. Lau, JPL 4800 Oak Grove Dr. Pasadena, California 91103	
Summary	

This project is to develop methods to slice silicon into sheet materials suitable for use as solar cells. The program is directed towards preparation of lowest silicon sheet by ingot slicing. The goals for this contract are: wafer thickness, 5 mils; slicing rate, 10 mils/minute; blade thickness, 3 mils; kerf loss, 5 mils; parallel loss, 100; wafer flatness and parallelism, < 2 mils; and wafer size, 4 in. diameter or 4 in. x 4 in. or 12 in.² Work to be done includes modifying and using an existing Varian 686 wafering machine for experimental evaluation of silicon slicing parameters such as: cutting load variations, slicing speed, blade dimensions, material properties and tension, abrasive sizes and concentration, lubricants, and specimen mounting.

Characterization/tests are to include: physical dimensional measurements, surface damage by etching, x-ray and optical, taper and surface roughness by profilometer, interference fringe count, and scanning electron microscope.

Goals were recently extended to include: ingot yield, 24 of 0.024 μ m thick wafers/lineal cm. of 12 cm diameter ingot; wafer productivity, one 12-cm diameter wafer/minute; flatness and parallelism, ASTM semiconductor slice standards; wafer thickness, 0.025 cm; blade life, vol. blade worn/vol. Si removed 0.035; slicing life, wt. Si abraded/wt. abrasive used $\geq 0.5 \geq 0.2$ kg Si abraded/liter oil.

Future work shall follow a similar direction as described above with the addition of: (1) designing and assembling a laboratory slicing machine; (2) designing and assembling blade alignment device; and (3) designing, assembling, and testing a prototype machine capable of slicing 900 simultaneous slices with the above-stated goals.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Westinghouse Electric Corporation Power Circuit Breaker Division Trafford, Pennsylvania	Title High-Capacity Arc Heater Process
Principal Investigator Name: Mr. Maurice Fey Phone: (517) 496-4907	Contract No. 954589
	Period of Performance July 29, 1976-March 1979
Work Location Trafford, Pennsylvania	Fiscal Year 1978 Funding \$845,721
Government Technical Representative and Address Anthony Briglio, Jr., JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$2,900,000

Summary

The objective of this contract is to establish the practicality of an arc heater process incorporating the reduction of silicon tetrachloride for the low-cost, high-volume production of solar cell grade silicon. In the performance of this project the contractor shall:

- a. Perform thermochemical analyses to obtain information on the conditions for maximum yields of silicon using the following reductants: sodium, magnesium, zinc, and hydrogen.
- b. Conduct a detailed analysis of the entire process for the production of silicon.
- c. Perform a purity analysis to correlate impurity levels in the product silicon with those in the process feedstocks.
- d. Characterize and analyze injection techniques for the two reactants, sodium (selected as the best reductant to use) and silicon tetrachloride.
- e. Conduct a detailed study and analysis of the reaction kinetics for the reduction of silicon tetrachloride by sodium.
- f. Investigate the reaction of sodium and silicon tetrachloride to obtain data on this reaction under conditions of the process.
- g. Design, construct, and test an experimental system for demonstrating the process.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Westinghouse Electric Corporation Research Laboratories 1310 Beulah Road Pittsburgh, Pennsylvania 15235	Title Phase II Automated Array Assembly Task
	Contract No. 954873
Principal Investigator Name: John Szedon Phone: (412) 256-3394	Period of Performance September 23, 1977-October 1978
Work Location Pittsburgh, Pennsylvania	Fiscal Year 1978 Funding \$425,173
Government Technical Representative and Address L.E. Sanchez, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$425,173

Summary

The objective of this contract is to develop and verify processes for making solar cells from dendritic web silicon ribbon. Emphasis is placed on the development of a Chemical Vapor Deposited (CVD) P+ back diffusion. The development of these processes will permit the technical and economic evaluation of silicon sheet material.

The specific contract goals are to:

- a. Perform detailed technical and cost analyses for an overall process sequence to convert silicon sheet material into solar array modules.
- b. Describe each process step within this sequence for input/output requirements/characteristics and relate these requirements/characteristics with those of the adjoining process step. Identify and describe the materials, supplies, and equipment utilized in each process step and the critical parameters of each.
- c. Determine those process steps for which significant design and development efforts, or proof of operation, are required to reach technical and economic readiness to realize the project goals.
- d. Define the type of verification required for each process step to demonstrate technological readiness.
- e. Manufacture solar cells and solar modules using the process steps and the process sequence specified.
- f. Provide input data for JPL's Solar Array Module Industry Cost Standards (SAMICS) Program.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Westinghouse Electric Corporation Research and Development Center Beulah Road Pittsburgh, Pennsylvania	Title Solar Cell Grade Si Definition
	Contract No. 954331
Principal Investigator Name: Dr. Richard Hopkins Phone: (412) 256-3235	Period of Performance October 1, 1975-February 1980
Work Location Pittsburgh, Pennsylvania	Fiscal Year 1978 Funding \$434,000
Government Technical Representative and Address Dr. Alan Yamkawa, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Cumulative Funding \$1,353,471

Summary

The objective of this program is to investigate the effects of impurities, various processes, and impurity-process interactions on the performance of terrestrial silicon solar cells in order to determine the purity requirement for a solar cell grade silicon. The program approach shall consist of: (1) the growth of singly-, doubly-, and multiply-doped silicon single crystals containing a baseline boron or phosphorous dopant and specific impurities; (2) assessment of these crystals by chemical, electrical, and solar cell measurements; (3) correlation of the impurity kind and level with crystal quality and device performance; (4) delineation of the role of impurities and processing on solar cell performance; and (5) determination of the combined effects of impurities and growth rate on the solar cell performance of silicon produced by dendritic web and Czochralski methods.

Contract Extension

The contractor shall make appropriate analytical, metallurgical, and electrical measurements, and shall incorporate into the studies a cell fabrication process which consistently yields baseline cells with uniform high-performance characteristics. The following general categories shall be included:

- a. Effects of cell processing.
- b. Effects of impurities on solar cells fabricated from n-type silicon.
- c. Effects of impurities on solar cells fabricated from p-type silicon.
- d. Anisotropy effects.
- e. Permanence of impurity and process effects.
- f. Using C technique, grow a minimum of 51 ingots doped with various sets of impurities and 10 baseline ingots.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Westinghouse Electric Corporation Beulah Road Pittsburgh, Pennsylvania 15235	Title Web Dendritic Process Development
	Contract No. 954654
Principal Investigator Name: Stu Duncan Phone: (412) 256-3666	Period of Performance April 20, 1977-December 1979
	Fiscal Year 1978 Funding \$692,869
Work Location Pittsburgh, Pennsylvania	Cumulative Funding \$1,122,869
Government Technical Representative and Address Dr. Thomas G. Digges, JPL 4800 Oak Grove Dr. Pasadena, California 91103	

Summary

The purpose of this contract is to develop methods of producing low-cost silicon sheet suitable for cost-effective solar cells by the Web Dendritic (WD) process. The objective of the operation of these machines and equipment shall be directed toward an interim through-put demonstration of 12 cm² per min.

The contractor will:

- a. Modify the existing WD machine and operate three other existing machines.
- b. Develop and utilize the capability of dynamic thermal trimming.
- c. Develop and utilize melt replenishment capabilities.
- d. Develop and optimize lid geometry.
- e. Give consideration to advanced thermal modeling of WD process, including both liquid and solid regions.
- f. Provide up to 100 solar cells (2 cm x 2 cm) made from selected ribbons as selected by JPL.

ELEMENT: Technology Development

SUB-ELEMENT: Low-Cost Solar Array

Prime Contractor and Address Xerox Corporation Electro-Optical Systems 300 N. Halstead St. Pasadena, California 91107	Title Center-Hole-Punched Solar Module Development Effort
Principal Investigator Name: William Martensen Phone: (213) 351-2725	Contract No. 954693
Work Location Pasadena, California	Period of Performance February 9, 1977-March 1978
Government Technical Representative and Address D.W. Boyd, JPL 4800 Oak Grove Dr. Pasadena, California 91103	Fiscal Year 1978 Funding \$24,677
	Cumulative Funding \$177,891

Summary

The objective of this contract was to design and fabricate a solar module that demonstrates a potential reduction in panel automated assembly costs by incorporating a mechanical interconnect scheme to eliminate the need for welding or soldering interconnects to solar cells.

In the performance of this effort, the contractor was to:

- a. Design a solar cell with a hole in the center of the cell for attachment by a current conducting stud.
- b. Ensure that the module is capable of performing within the environmental limits set forth in JPL Document 5-342-1B entitled "Silicon Solar Cell Module Performance, Environmental Test and Inspection Requirements."
- c. Fabricate and deliver six modules with aluminum-backed cells and six modules with silver-titanium-palladium-backed cells.
- d. Provide input data for the JPL Solar Array Module Industry Cost Standards (SAMICS) Program.

Concentrator Systems

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ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address AAI Corporation P. O. Box 6767 Baltimore, Maryland 21204	Title 10 Kilowatt Central Receiver Array
	Contract No. Sandia 05-6399
Principal Investigator Name: H. Wilkening Phone: (301) 666-1400	Period of Performance December 1, 1977-October 31, 1978
Work Location Baltimore, Maryland	Fiscal Year 1978 Funding \$252,200
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$252,200

Summary

This project entails the design phase of a 10 kilowatt central receiver photovoltaic array. The baseline design employs compound curved heliostats to focus the energy onto a receiver. Each receiver generates about 3.3 kW and operates at 200 suns. The heliostats are tilted to achieve elevation tracking, and the whole module, mirrors, and receiver are rotated on a turntable to achieve azimuthal tracking.

ELEMENT: Technology Development
SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Acurex Corporation 485 Clyde Ave. Mountain View, California	Title Parabolic Trough PV Concentrator Commercialization
	Contract No. 07-7031
Principal Investigator Name: William Masters Phone: (415) 964-3200	Period of Performance March 2, 1978-October 1, 1978
Work Location Mountain View, California	Fiscal Year 1978 Funding \$80,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$90,000

Summary

The purpose of this contract is to develop a design for a photovoltaic/thermal receiver suitable for operation in the standard Acurex parabolic trough module, and for the fabrication and testing of this parabolic trough photovoltaic concentrator module. Under the contract, two receivers are being designed and tested. The first incorporates a solar cell assembly designed in conjunction with SCRA; this cell assembly incorporates a clampon aluminum-extruded substrate to which the cells are attached. The second receiver has been designed and built by Solarex Corporation; it is very similar to a photovoltaic/thermal receiver tube they are manufacturing for another photovoltaic concentrator project. Both receiver tubes are being delivered to Sandia Laboratories for testing and evaluation mounted in standard 4 ft. x 10 ft. Acurex parabolic troughs.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Acurex Corporation 485 Clyde Ave. Mountain View, California	Title Sealed Glass Concentrator Module Development
Principal Investigator Name: William Masters Phone: (415) 964-3200	Contract No. 07-6922
Work Location Mountain View, California	Period of Performance February 1, 1978-October 31, 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$130,000
	Cumulative Funding \$169,000

Summary

The objective of this project is to develop a photovoltaic concentrator module which essentially utilizes technology similarly employed in the manufacture of sealed beam auto and aircraft headlights. The project is determining the feasibility of designing and fabricating photovoltaic concentrator modules which are 8 inches in diameter. They consist of a transparent glass cover fused to a silvered glass reflector, with a concentrator silicon cell mounted at the focus of the parabolic dish reflector element. The advantages of this concept are that: (1) it utilizes an extremely well-developed fabrication technology; (2) it provides an ideal environment for both the silvered reflector and the solar cell; and (3) it results in a module which is very easily replaceable in the case of a failure.

ELEMENT: Technology Developments

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Arco Solar, Inc. 9701 Lurline St. Chatsworth, California	Title Design and Fabrication of Prototype Combined PV/Thermal Non-Tracking Collectors
	Contract No. Sandia 07-6919
Principal Investigator Name: Matt Van Luewen Phone: (213) 998-0667	Period of Performance November 11, 1977-August 10, 1978
Work Location Chatsworth, California	Fiscal Year 1978 Funding \$59,012
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding
	\$59,012

Summary

The purpose of this contract has been to obtain, for purposes of test and evaluation, combined photovoltaic/thermal flat-panel collectors suitable for roof-mounted operation. Both air-and water-cooled collectors (two modules each) have been provided under this contract. Each of these types is based on commercially available thermal collectors with modifications to the absorber plate for accommodating the photovoltaic cells. These collectors represent the simplest approach to combined collector design and serve to provide the low-efficiency limit to the operation data. Hardware delivery occurred in mid-May 1978.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address University of Arizona Tucson, Arizona	Title Sectored Reflective Dish PV Module Development
Principal Investigator Name: R. Call Phone: (602) 884-2482	Contract No. 13-0211 Period of Performance May 24, 1978-December 31, 1978
Work Location Tucson, Arizona	Fiscal Year 1978 Funding \$27,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$57,000

Summary

The purpose of this contract is to develop a module which is similar to the Cassegrain module being proposed for incorporation in the Arizona Public Service photovoltaic concentrator applications experiment at the Phoenix airport. This module design incorporates a reflective dish concentrator consisting of a horizontal section of cones. The receiver consists of cells mounted on the perimeter of a polygonal pedestal. Under this contract, suitable cell laydown techniques are being identified and a complete module is being fabricated and tested.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address California Institute of Technology Pasadena, California 91103	Title Fluorescent Concentrator Study
	Contract No. 07-7270
Principal Investigator Name: Ahmad Zewail Phone: (213) 795-6811 x2536	Period of Performance May 15, 1978-May 30, 1979
Work Location Pasadena, California	Fiscal Year 1978 Funding \$40,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$87,000

Summary

The purpose of this project is to develop a basic understanding of the luminescent solar concentrator concept. The project will attempt to thoroughly characterize the various energy transfer mechanisms involved in luminescing dyes doped into suitable hosts for luminous concentrators. These mechanisms will be characterized with respect to dye concentrations by mixtures, dye host interactions, lifetimes, etc. This study represents a complement to an experimental investigation of luminescent solar concentrators being conducted by Owens-Illinois under contract no. 07-6921.

ELEMENT: Technology Development
SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address General Electric Company Advanced Energy Programs P.O. Box 8661 Philadelphia, Pennsylvania 19101	Title Concentrating Array Production Process Design
Principal Investigator Name: Ronald C. Hodge Phone: (215) 962-3814	Contract No. Sandia 07-6920
Work Location Valley Forge, Pennsylvania	Period of Performance October 14, 1977-November 13, 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$240,000
	Cumulative Funding \$250,000

Summary

General Electric has been funded to design concentrator arrays for large-scale production and to design the manufacturing processes to be used for fabrication. The emphasis is on basic parabolic troughs, circular Fresnel lenses, and parabolic dishes. The primary objective of the study is to determine how array cost and design are influenced by level of production. Secondary objectives are: (1) to find how energy cost depends on array size, concentration ratio, and tracking configuration; and (2) to compare the three basic concentrator types to see if one has inherent advantages over the others.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Honeywell Corporation 2600 Ridgeway Parkway Minneapolis, Minnesota 55413	Title 10 Kilowatt Actively Cooled PV Concentrator System
	Contract No. 07-7293
Principal Investigator Name: R.W. Jaminski Phone: (612) 378-5496	Period of Performance September 8, 1978-June 8, 1979
Work Location Minneapolis, Minnesota	Fiscal Year 1978 Funding \$326,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$326,000

Summary

The purpose of this project is the design of a 10 kilowatt actively cooled photovoltaic concentrator array. The proposed design is a parabolic trough design that has two-axis tracking via a center mount pedestal which provides Az-El tracking. Sagged, second surface silvered Corning 0317 glass constitutes the baseline reflective surface. The unit is required to produce 50 kW of thermal energy in addition to 10 kW electrical energy. The thermal output is with the outlet coolant temperature at 150°F.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Martin Marietta Corporation P.O. Box 179 Denver, Colorado 80201	Title 10 kW Fresnel Lens PV Array
Principal Investigator Name: R. Donovan Phone: (303) 973-4658	Contract No. 07-7265
Work Location Denver, Colorado	Period of Performance June 15, 1978-February 28, 1979
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$389,600
	Cumulative Funding \$389,600

Summary

This contract is for the fabrication of a 10 kilowatt concentrator array. The photovoltaic modules use Fresnel lenses to concentrate energy onto silicon solar cells. The system operates at a net concentration of 40 suns and uses passive cooling to maintain reasonable cell temperature. Two-axis tracking is of the Az-El type, with pedestal mount used to track 2.2 kW modules.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Motorola, Inc. Government Elect. Division 8201 East McDowell Rd. Scottsdale, Arizona 85252	Title Hybrid Solar Tracker
Principal Investigator Name: William Hochgraef Phone: (602) 949-2610	Contract No. Sandia 13-0203
	Period of Performance May 10, 1978-December 31, 1978
Work Location Scottsdale, Arizona	Fiscal Year 1978 Funding \$48,100
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$48,100

Summary

This work is intended to develop a hybrid solar tracking unit that will be adaptable to a large variety of concentrating arrays. The unit will combine the accuracy of closed-loop active tracking with the reliability of open-loop synthetic tracking. It will take advantage of Motorola's experience in microprocessor-based systems and will be inexpensively mass-producible. It will be modular in nature so that it may be easily modified for a wide variety of array types and drive motor types.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Motorola, Inc. Solar Operations 5005 East McDowell Road Phoenix, Arizona 85252	Title Silicon Concentrator Solar Cell Manufacturing Development
Principal Investigator Name: Larry Grenon Phone: (602) 244-5571	Contract No. Sandia 07-7079
	Period of Performance January 4, 1978-January 4, 1979
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$236,677
Government Technical Representative and Address: Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$236,677

Summary

The objective of this project is to develop manufacturing processes for fabricating high-performance, long-life single-crystal silicon solar cells for operation in solar concentrator systems.

The cell being developed has a n-type diffused layer on a p-type base of 0.2 to 0.5 Ωcm resistivity material. The front surface is texturized with a silicon nitride antireflection coating. The metalization system consists of plated palladium, nickel, and silver. Texturizing techniques have been developed to give a very uniformly texturized surface on which grid line definition of 1 mil has been accomplished.

ELEMENT: Technology Development
SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Motorola, Inc. Government Elect. Division 8201 East McDowell Rd. Scottsdale, Arizona 85252	Title Two-Axis Tracking Array
Principal Investigator Name: William W. Hochgraef Phone: (602) 949-2610	Contract No. Sandia 13-0202
Work Location Scottsdale, Arizona	Period of Performance May 1, 1978-November 1, 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$48,600
	Cumulative Funding \$48,600

Summary

The purpose of this work is to design and construct a two-axis tracking platform suitable for mounting various concentrator modules. While the prototype unit will be used for test purposes, every effort is being made to build the unit from commercially available standard parts at minimum cost consistent with safe operation. Since the platform can be used to mount a variety of concentrator modules, it is anticipated that potential concentrator array manufacturers might build similar platforms for their products (using the designs obtained in this contract) or purchase the unit directly from Motorola.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address North Carolina Agriculture and Technical State University Greensboro, North Carolina	Title Solar Cell Evaluation
Principal Investigator Name: Prof. W.E. Alexander Phone: (919) 379-7760	Contract No. Sandia 07-8052
Work Location Greensboro, North Carolina	Period of Performance February 1978-September 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$15,000
	Cumulative Funding \$15,000

Summary

The objective of this project has been to carry out performance characterization measurements on concentrator solar cells and to evaluate the long-term stability and reliability of concentrator cells. In this first period, the appropriate experimental capabilities have been established. A heating/cooling stage for studying the effects of thermal cycling on solar cell integrity has been tested over a 100°C cycle. Another test holder for steady-state temperature control has been designed for operation from 77° to 600°K and is partially assembled. The design included temperatures as high as 600°K to allow testing of wide bandgap solar cells at the higher temperatures of interest to combined thermal/photovoltaic systems. Plans are being formulated for an outdoor solar cell test facility on top of a building which would utilize the Fresnel lens design being developed for use at Sandia.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Owens-Illinois P.O. Box 1035 Toledo, Ohio 43666	Title Luminescent Photovoltaic Concentrator Development
	Contract No. 07-6921
Principal Investigator Name: Charles Rapp Phone: (419) 247-8906	Period of Performance March 1, 1978-October 31, 1978
Work Location Toledo, Ohio	Fiscal Year 1978 Funding \$130,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$150,000

Summary

This is an experimental study whose primary objective is to assess the feasibility of using luminescent dyes doped in suitable plastic or acrylic substrates to absorb solar radiation. This material with total internal reflection capacity will transmit the luminesced radiation to the sides of the material where it can be converted to electricity via a solar cell. A unique feature of the Owens-Illinois approach to this solar concentrator concept is their use of very thin films of dye host materials laminated upon thicker, transparent substrate materials such as sheet acrylic. Preliminary analyses indicate such luminescent photovoltaic concentrators can be manufactured at array prices of approximately \$.50/Wp with efficiencies on the order of 5 percent. This study is investigating various dye/host/substrate combinations and analyzing on problems in changing the collector area, dye stability, and dye lifetimes.

ELEMENT: Technology Development
SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address RCA Corporation David Sarnoff Research Center P.O. Box 432 Princeton, New Jersey 08540	Title Laminated Fresnel Lens Development
Principal Investigator Name: L. Napoli Phone: (609) 452-2700 x3212	Contract No. 07-7144
	Period of Performance February 10, 1978-August 10, 1978
Work Location Princeton, New Jersey	Fiscal Year 1978 Funding \$50,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$50,000

Summary

This project called for the development of Fresnel lenses which are formed by molding optical grade expoxies into facets directly on a glass substrate. These facets are formed by bringing an RTV negative master of the facets into intimate contact with the glass plate. The facet voids are then evacuated and subsequently filled with epoxy. The project demonstrated that good optical quality lenses can be formed in this manner.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Research Triangle Institute Research Triangle Park, North Carolina 27709	Title Novel Concentrator Photovoltaic Converter System Development
	Contract No. Sandia 07-7149
Principal Investigator Name: Mr. M.F. Lamorte Phone: (919) 541-5900	Period of Performance January 24, 1978-January 23, 1979
Work Location Research Triangle Park, North Carolina	Fiscal Year 1978 Funding \$226,800
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$226,800

Summary

This contract is part of an overall program to explore novel solar cell or photovoltaic converter system concepts which have the potential of conversion efficiencies greater than 25 percent. In this program, proof-of-concept of the cascading solar cell concept for achieving high photovoltaic conversion efficiencies is emphasized. In the cascading cell approach, two solar cells are stacked and joined by an intermediate, electrically shorting layer to form a monolithic structure. Theoretical studies will support the experimental work to define the optimum selection of material and device parameters. An important step in proving the cascade cell approach will be the demonstration of the summing of individual solar cell open-circuit voltages through the intermediate electrically shorting junction.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Rockwell International Science Center Thousand Oaks, California 91360	Title Gallium Arsenide PV Dense Array for Concentrator Applications
	Contract No. Sandia 07-7274
Principal Investigator Name: Dr. John Cape Phone: (805) 498-4545	Period of Performance June 15, 1978-June 15, 1979
Work Location Thousand Oaks, California	Fiscal Year 1978 Funding \$399,800
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$399,800

Summary

The objective of this program is the design and fabrication of a 20 kWe GaAs cell dense array with integral heat sinking to be tested on the central tower receiver facility called the Solar Thermal Test Facility (STTF) at Sandia Laboratories. Based upon current state-of-the-art GaAs cell technology, the array is designed to produce 20 kWe under 1000 kW/m² illumination (approximately Air Mass 1) at a cell temperature of 40°C; an output voltage of 240 Vdc and an overall array efficiency above 17 percent is expected. The array is to be capable of being tested at illumination levels from 1 kW/m² up to 1500 kW/m² and at temperatures from 25°C up to 180°C. Special emphasis is placed on the system-related considerations such as electrical interconnections, integral heat sinking, optical packing efficiency, and cell production capability. The array is of modular design, consisting of four 5 kW panels connected in parallel. Each panel contains 16 linear modules electrically connected in series. The individual modules consists of 16 series-connected, 1.0 x 1.25 cm² active area GaAs cells mounted on an integral heat sink.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Selectro-Thermo, Inc. 1934 Lakeview Ave. Dracut, Massachusetts 01826	Title STI PV Array
	Contract No. Sandia 13-0222
Principal Investigator Name: Arthur J. Manelas Phone: (617) 957-0028	Period of Performance May 15, 1978-February 15, 1979
Work Location Dracut, Massachusetts	Fiscal Year 1978 Funding \$12,408
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$13,740

Summary

This contract calls for the purchase of one Selectro-Thermo Model A160-6 160 ft² concentrating photovoltaic array with a battery and for two 16 ft² modules for the A160-6 array. Installation consulting is also included. The array will be installed at the Photovoltaic Advanced Systems Test Facility and will be evaluated along with various other test arrays.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Solarex 335 Piccard Dr. Rockville, Maryland 20850	Title Solar Cell Manufacture
Principal Investigator Name: C.Y. Wrigley Phone: (301) 948-0202	Contract No. Sandia 05-6391
	Period of Performance October 1, 1977-October 1, 1978
Work Location Rockville, Maryland	Fiscal Year 1978 Funding \$289,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$289,000

Summary

The objective of this project is to develop manufacturing procedures for mass producing silicon solar cells of high power conversion efficiency.

The cell is an n^+p made by processing a Czochralski-grown wafer with a base resistivity of 0.3 ohm-cm. Two geometries (rectangular and circular) are being constructed with anticipated efficiencies of at least 13 percent at 50 suns.

Characterization of the cells will be carried out at Sandia Laboratories-Albuquerque and NASA Lewis Research Center following delivery of 1,000 cells of each type.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Spectrolab, Inc. 12500 Gladstone Ave. Sylmar, California 91432	Title Design and Fabrication of Prototype Combined Photovoltaic/ Thermal Non-Tracking Collectors
	Contract No. Sandia 07-6929
Principal Investigator Name: Harold R. Jandorf Phone: (213) 365-4611 x213	Period of Performance November 7, 1977-August 6, 1978
Work Location Sylmar, California	Fiscal Year 1978 Funding \$97,258
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$97,258

Summary

The purpose of this contract was to obtain combined photovoltaic/thermal flat panel collectors suitable for roof-mounted operation for purposes of test and evaluation. The modules are air cooled by use of a design evolved as a result of some system optimization work. While use was made of previous thermal collector design work, the collector design was developed with the photovoltaic segment properties in mind from the beginning. The resulting collector represents the initial attempts at an optimized photovoltaic/thermal combined collector. Hardware delivery occurred in mid-May 1978.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrators Systems

Prime Contractor and Address Spectrolab, Inc. 12500 Gladstone Ave. Sylmar, California 91342	Title Hybrid Photovoltaic/Thermal Electric Analysis
	Contract No. 05-6196
Principal Investigator Name: Jack Castle Phone: (213) 365-4611	Period of Performance November 1, 1977-October 31, 1978
Work Location Sylmar, California	Fiscal Year 1978 Funding \$210,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$231,000

Summary

The objective of this study is to determine whether combining photovoltaic and thermodynamic conversion techniques in a single solar-electric system is more cost effective than solar photovoltaic or solar thermal electric schemes individually. The fundamental problem facing such a hybrid system is the need to maintain the photovoltaic array at a moderate temperature in order not to degrade its efficiency while collecting sufficient, high-grade thermal energy to allow a reasonable thermodynamic conversion efficiency. This study will develop several conceptual designs of hybrid photovoltaic/solar thermal systems and will analyze their performance potentials. The cost estimates of electrical energy produced by such systems will be compared with current cost estimates for other solar electric technologies.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Spectrolab, Inc. 12500 Gladstone Ave. Sylmar, California 91342	Title Polar-Mounted PV Parabolic Trough Commercialization
	Contract No. 07-7168
	Period of Performance May 1, 1978-June 30, 1979
Principal Investigator Name: Jack Castle Phone: (213) 365-4611	
Work Location Sylmar, California	Fiscal Year 1978 Funding \$50,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$141,000

Summary

Under a previous, photovoltaic 10 kW concentrator design development contract, Spectrolab designed a 1/2 parabola module which includes a compound elliptical concentrating secondary. Under this contract, they will redesign this concentrator for utilization in stand-alone applications of approximately 450 Wp. The redesign will incorporate two off-axis primary half parabola concentrators and two secondary concentrator/photovoltaic elements mounted along the focal lines of the two primaries. The entire module will be mounted in a polar tracking orientation. Three prototypes will be assembled also. One of these will be tested at Spectrolab, one will be tested at Sandia, and one will be tested at a typical remote location. In addition, considerable analyses of the durability and reliability of this module and its components will be conducted. The contract also calls for the careful study of suitable fabrication techniques for this array. The array will be available for commercial sales at the end of the contract.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Spectrolab 12484 Gladstone Ave. Sylmar, California 91342	Title Ten kW Photovoltaic Concentrator
	Contract No. 07-7266
Principal Investigator Name: N. Grossman Phone: (213) 365-4611	Period of Performance July 10, 1977-April 10, 1978
Work Location Sylmar, California	Fiscal Year 1978 Funding \$460,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico 87185	Cumulative Funding \$460,000

Summary

The objective of this contract was the fabrication of a 10 kilowatt array which utilizes an off-axis half-parabolic trough and is passively cooled. Azimuth tracking was accomplished by mounting the full 10 kW array on a carousel. Elevation tracking was achieved by pivot in the rows of troughs parallel to their longitudinal axis.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Sun Trac Corporation 1674 South Wolf Road Wheeling, Illinois 60090	Title Sphere Enclosed CPC Photovoltaic Concentrator Commercialization
	Contract No. 07-7167
Principal Investigator Name: D. Moeller Phone: (312) 541-2095	Period of Performance February 13, 1978-November 30, 1978
Work Location Wheeling, Illinois	Fiscal Year 1978 Funding \$120,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$157,000

Summary

Sun Trac Corporation is a company which independently developed and manufactured a photovoltaic two-axis tracking concentrator array for oilwell cathodic protection a few years ago. The array design incorporated a conical reflector with a concentration ratio of about 10, and a concentrator matrix formed by such conical concentrators enclosed in an acrylic sphere. Under this contract, Sun Trac is developing a new enlarged version of this same array. The new concentrator will utilize $\frac{1}{4}$ inch silicon cells operating behind a two-stage CPC reflective and refractive concentrator with a geometric concentration ratio of 115. This new array will be enclosed in an acrylic sphere which is $8\frac{1}{2}$ feet in diameter. The contract objective is to develop this new array design, fabricate a prototype, and prepare for limited production of these arrays for commercial sales.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Swedlow, Inc. 12122 Western Ave. Garden Grove, California 92645	Title 2000:1 Fresnel Lens
	Contract No. 13-0299
Principal Investigator Name: A. Antista Phone: (714) 893-7531	Period of Performance August 10, 1978-February 10, 1979
Work Location Garden Grove, California	Fiscal Year 1978 Funding \$50,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$50,000

Summary

This contract calls for the development of a Fresnel lens capable of producing concentration ratios of 125, 250, 500, 750, 1,000, 1,250, 1,500, 1,750, and 2,000 suns over a target area of 1 inch in diameter. At each of these concentration ratios, the flux uniformity at the target will be flat within plus or minus 5 percent. These 54-inch diameter lenses will facilitate testing GaAs and other cells designed to operate at high concentration ratios.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Swedlow, Inc. 12122 Western Ave. Garden Grove, California 92645	Title Fresnel Lens Analyzer Design Fabrication
Principal Investigator Name: D. Holdridge Phone: (714) 893-7531	Contract No. Sandia 07 6083
Work Location Garden Grove, California	Period of Performance January 25, 1978-December 31, 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$54,600
	Cumulative Funding \$54,600

Summary

The objective of this program is to design a Fresnel lens analyzer to rapidly test and quantify the characteristics of Fresnel lenses. The unit will permit quantitative measurement as to the distribution of the flux produced by the lens when uniformly illuminated by a uniform artificial light source. The artificial light source is being tailored to closely reproduce the solar spectrum in the area of interest.

ELEMENT: Technology Development

SUB-ELEMENT: Concentrator Systems

Prime Contractor and Address Varian Associates, Inc. 611 Hanson Way Palo Alto, California 94303	Title Novel Concentrator Photovoltaic Converter System
Principal Investigator Name: Dr. L.W. James Phone: (415) 493-4000	Contract No. Sandia 07-6953
Work Location Palo Alto, California	Period of Performance December 7, 1977-December 6, 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico 87185	Fiscal Year 1978 Funding \$233,000
	Cumulative Funding \$233,000

Summary

This contract is part of an overall program to explore novel solar cell or photovoltaic converter system concepts which have the potential of conversion efficiencies greater than 25 percent. In this program, a two-cell photovoltaic converter using direct spectral splitting of the solar spectrum will be demonstrated, with a prototype converter delivered to Sandia at the end of a 12-month development program. Experimental and theoretical studies are being carried out to define the performance expectations of multijunction converter concepts, with emphasis on the crucial technologies needed for higher performance, lower cost approaches to the high-efficiency spectral-splitting solar converter.

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System Definition and Development

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ELEMENT: System Definition and Development

Prime Contractor and Address Abacus Controls, Inc. P.O. Box 893 Somerville, New Jersey 08876	Title 10 kVa Power Conditioning Unit
Principal Investigator Name: George A. O'Sullivan Phone: (201) 526-6010	Contract No. Sandia 13-0231
Work Location Somerville, New Jersey	Period of Performance June 10, 1978-April 15, 1979
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$12,000
	Cumulative Funding \$30,460

Summary

This work involves the modification of the 10 kVa transistorized inverter developed under NASA contract in order to make it more reliable and versatile. Heavier transistors will be used and closed-loop maximum power tracking will be implemented in the utility inter-tie mode. The unit will be delivered to Sandia's Photovoltaic Advanced System Test Facility for evaluation, and Abacus Controls, Inc. will market the unit under the trade-name "Sunverter."

ELEMENT: System Definition and Development

Prime Contractor and Address Arizona State University Tempe, Arizona 85281	Title PV Subsystem Model and Load Study
Principal Investigator Name: D.L. Evans Phone: (602) 965-3291	Contract No. Sandia 13-0313
	Period of Performance July 17, 1978-July 17, 1979
	Fiscal Year 1978 Funding \$58,300
Work Location Tempe, Arizona	Cumulative Funding \$58,300
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	

Summary

The purposes of this solar photovoltaic study are to investigate simplifications in the modeling of photovoltaic subsystem components and to assess design sensitivity to system electrical load variations. In the first task, computer models of the PV array, battery, regulator, and inverter are to be studied. The objectives are to establish simplified computational techniques without loss of accuracy and to compare these with existing component models and results. The second task involves a study of the effect of variations in the assumed load profile on photovoltaic system designs. Both repeatable and random loads will be studied to determine their effects on predicted system performance. Shifts in the time of peak load demand and variations in peak-to-average load ratios will also be explored. The results will indicate how the system design can be modified to accommodate these load changes.

ELEMENT: System Definition and Development

Prime Contractor and Address Arizona State University Mechanical Engineering Department Tempe, Arizona 85281	Title Solar Photovoltaic Test and Evaluation Program
Principal Investigator Name: C. Backus Phone: (602) 965-3857	Contract No. 05-6037
Work Location Tempe, Arizona	Period of Performance February 1, 1978-December 1, 1979
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$120,000
	Cumulative Funding \$120,000

Summary

This program is a general program that includes cell technology evaluation, array testing, thermal analysis and testing, in addition to experimental program consulting and proposal review.

ELEMENT: System Definition and Development

Prime Contractor and Address The BDM Corporation 2600 Yale Blvd., S.E. Albuquerque, New Mexico 87106	Title Analysis of Design Tradeoffs and Transient Effects in Large Photovoltaic Arrays
	Contract No. Sandia 07-6941
Principal Investigator Name: M.G. Semmens Phone: (505) 843-7870	Period of Performance December 6, 1977-December 5, 1978
	Fiscal Year 1978 Funding \$290,300
Work Location Albuquerque, New Mexico	Cumulative Funding \$290,300

Summary

The contract provides for the development of a computer code to simulate large photovoltaic arrays. The simulation will be based on single cell characteristics and will allow the interconnection of cells into modules and modules into arrays. It will simulate illumination transients to model the effects of clouds and lightning flashes, and will model temperatures that can be expected in terrestrial environments. A user's guide for this code will be provided. The code will be exercised to investigate design tradeoffs and transient effects in large photovoltaic arrays. Critical parameters effecting system reliability, safety, and performance will be identified.

ELEMENT: System Definition and Development

Prime Contractor and Address BDM Corporation McLean, Virginia 22101	Title PV Applications Definition and PV System Definition Study in the Agriculture Sector
	Contract No. Sandia 07-6951
Principal Investigator Name: R.W. Mengel Phone: (703) 821-5078	Period of Performance December 6, 1977-December 5, 1978
	Work Location McLean, Virginia
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Fiscal Year 1978 Funding \$221,100
	Cumulative Funding \$221,100

Summary

The objectives of this study are to identify promising electrical loads in the agricultural sector that can be supplied with solar photovoltaic energy and to provide conceptual designs of photovoltaic power systems for chosen applications. As part of this effort a data base of energy-use patterns in agriculture is to be assembled. Agricultural sub-sectors are to be identified, load profiles for typical applications are to be generated, and four applications are to be selected for conceptual designs of photovoltaic systems. Results are to reflect primarily electrical energy usage patterns, although there will be some analysis on combined systems using electrical and thermal energy.

ELEMENT: System Definition and Development

Prime Contractor and Address BDM Corporation 2600 Yale, S.E. Albuquerque, New Mexico 87106	Title PV Programming Support Services
Principal Investigator Name: Ellan A. Anderson Phone: (505) 843-7870	Contract No. Sandia 13-0254
	Period of Performance May 30, 1978-November 30, 1978
Work Location Albuquerque, New Mexico	Fiscal Year 1978 Funding \$15,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	Cumulative Funding \$22,000

Summary

The contract is to provide programming support for in-house photovoltaic analysis. Programming support consists of code modifications, program operations, and documentation on code changes. Also included are code checkouts, comparison of results, and maintenance of program files.

ELEMENT: System Definition and Development

Prime Contractor and Address Bechtel Corporation 50 Beale St. San Francisco, California 94105	Title Battery Storage Performance Requirements for Terrestrial Solar Photovoltaic Power Systems
	Contract No. 31-109-38-2962
Principal Investigator Name: W.J. Stolte Phone: (415) 768-5430	Period of Performance October 1976-September 1977
	Fiscal Year 1978 Funding \$58,000
Work Location San Francisco, California	Cumulative Funding \$58,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	

Summary

This project consisted of a study to assess the performance requirements for near-and mid-term batteries for application to solar photovoltaic application to solar photovoltaic power systems. The study evaluated a broad spectrum of photovoltaic applications in terms of the types of loads served and the characteristics of the system components. Four applications, representative of low, intermediate, and high power systems, were examined in detail. The characteristics for the batteries in each application were determined, and an economic analysis was made to determine the allowable battery break-even costs. The study identified the most promising battery/solar systems application and specific battery technologies that require development; it also presented guidelines for a development program.

ELEMENT: System Definition and Development

Prime Contractor and Address Bechtel National, Inc. 50 Beale St. San Francisco, California 94105	Title Requirement Definition and Preliminary Design of a PV Central Power Station Experimental Test
	Contract No. Sandia 07-6926
Principal Investigator Name: John Ruzek Phone: (415) 768-6931	Period of Performance November 16, 1977-November 15, 1978
	Fiscal Year 1978 Funding \$250,000
Work Location San Francisco, California	Cumulative Funding \$315,749
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	

Summary

This work consists of the physical and electrical design and site specifications for a 1 to 2 MWe photovoltaic central power station. The physical and electrical design studies are to emphasize the experimental nature of the plant. This requires that the facilities be capable of incorporating numerous types of prototype photovoltaic collectors, both concentrating and non-concentrating, as well as hybrid. In addition, the capability of incorporating a direct utility connection is necessary. The preliminary design is to include identification of all necessary equipment, data gathering systems; wiring, plumbing, site preparation, and structures to support these requirements. Maximum flexibility in configuration is desired, as is the option of eventual site expansion. The site specification effort will identify the necessary attributes for ideal site location. This list will serve as a guideline for eventual site selection. This entire study is being conducted in close cooperation with utility representatives and will include the reviews and comments of at least ten utilities in the final report.

ELEMENT: System Definition and Development

Prime Contractor and Address General Electric Co. Advanced Energy Programs, Space Division P.O. Box 8661 Philadelphia, Pennsylvania 19101	Title Requirement Definition and Preliminary Design of a PV Central Power Station Experimental Test Facility
	Contract No. Sandia 07-6925
Principal Investigator Name: George O'Brien Phone: (215) 962-1276	Period of Performance December 6, 1977-December 5, 1978
Work Location Valley Forge, Pennsylvania	Fiscal Year 1978 Funding \$240,000
Government Technical Representative and Address Sandia Laboratories. Albuquerque, New Mexico 87185	Cumulative Funding \$318,900

Summary

This work consists of the physical and electrical design and site specifications for a 1 to 2 MWe photovoltaic central power station. The physical and electrical design studies are to emphasize the experimental nature of the plant. This requires that the facilities be capable of incorporating numerous types of prototype photovoltaic collectors, both concentrating and non-concentrating, as well as hybrid. In addition, the capability of incorporating direct utility connection is necessary. The preliminary design is to include identification of all necessary equipment, data gathering systems, wiring, plumbing, site preparation, and structures to support these requirements. Maximum flexibility in configuration is desired, as is the option of eventual site expansion. The site specification effort will identify the necessary attributes for ideal site location. This list will serve as a guideline for eventual site selection. This entire study is being conducted in close cooperation with utility representatives and will include the reviews and comments of at least ten utilities in the final report.

ELEMENT: System Definition and Development

Prime Contractor and Address MIT Lincoln Laboratory 244 Wood Street Lexington, Massachusetts 02173	Title Solar Photovoltaic Field Tests and Applications Project
	Contract No. EY-76-C-02-4094.A006
Principal Investigator Name: M.D. Pope Phone: (617) 862-5500 x7785	Period of Performance October 1, 1977-December 31, 1978
	Fiscal Year 1978 Funding \$3,999,000
Work Location Lexington, Massachusetts	Cumulative Funding \$7,179,000
Government Technical Representative and Address DOE - Div. of Distributed Solar Tech. 600 E Street, NW, Washington, D.C. 20545	

Summary

The objective of this contract is to establish technical feasibility of photovoltaic (PV) power systems in a variety of applications. MIT/Lincoln Laboratory will: (1) design, test and evaluate PV systems; 2) identify and eliminate the technical and institutional constraints to the acceptance of PV systems; and 3) interface with other major contractors on all aspects of the National PV Program which are pertinent to this project.

To accomplish these objectives, MIT/Lincoln Laboratory will direct the design, construction, and operation of several experimental PV power systems. These will include: (1) a residential test facility; (2) a 100 kW peak system at Natural Bridges National Monument in Southeastern Utah; (3) a PV powered AM radio station; and (4) continued operation and evaluation of the 25 kW peak Agricultural Test Facility in Nebraska. In addition, MIT/Lincoln Laboratory will actively participate in the areas of: (1) data acquisition, power conditioning and control; and (2) materials, processes, and testing in support of these field tests.

ELEMENT: System Definition and Development

Prime Contractor and Address Mission Research Corporation 1400 San Mateo Blvd., S.E. Albuquerque, New Mexico 87108	Title Analysis of the Effects of Lightning on Solar Photovoltaic Arrays
	Contract No. Sandia 13-0215
Principal Investigator Name: Dr. John M. Hamm Phone: (505) 265-8306	Period of Performance May 1, 1978-April 30, 1979
	Fiscal Year 1978 Funding \$97,700
Work Location Albuquerque, New Mexico	Cumulative Funding \$97,700
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico 87185	

Summary

The principal objectives of this contract are:

- a. To determine the responses of the complete array system and its sub systems to the lightning environment.
- b. To determine lightning protection schemes and hardness design criteria for the complete system.

A literature and industry survey will be performed to determine cell modules and cell vulnerability, and modern array system design concepts. Source models will be developed in order to describe the optical and electromagnetic transient environments. The models will be exercised to determine the transient currents and voltages associated with individual cells and load components. Preferred interconnection, schemes, cable routing, and grounding practices will be provided. Finally, general protection criteria and strategies will be developed.

ELEMENT: System Definition and Development

Prime Contractor and Address University of Nebraska Lincoln, Nebraska 68588	Title Solar-Cell-Powered Irrigation Pumping Plant and Other Alternate Uses
Principal Investigator Name: Professor Paul E. Fishbach Phone: (402) 472-1626	Contract No. BX 192 Period of Performance May 1, 1978-December 31, 1978
Work Location Mead, Nebraska	Fiscal Year 1978 Funding \$102,724
Government Technical Representative and Address MIT/Lincoln Laboratory 244 Wood Street Lexington, Massachusetts 02173	Cumulative Funding \$249,082

Summary

The objective of this contract is to operate and maintain the 25 kW solar-cell-powered system installed by DOE at the University of Nebraska experimental energy farm located at Mead, Nebraska. The PV system is being used for crop irrigation and crop drying. The University also has written an operations manual for the PV system.

To achieve these objectives, the University is providing on-site personnel to inspect, operate, and maintain the system. During the summer months of 1978, the University wrote, edited, and compiled a complete operations manual for the site, including an overall description of the demonstration projects.

Normally, irrigation systems are designed to operate at a uniform speed (rpm) to supply a constant flow of water at a given pressure to the irrigation system. Tests are being made using variable speed motors on the pumping plan, as well as other techniques to provide better compatibility with daytime insolation. Similarly, studies and tests are being conducted using two grain-drying bins located nearby to determine techniques of applying limited fan operation to conserve power and be compatible with daytime insolation.

ELEMENT: System Definition and Development

Prime Contractor and Address Sandia Laboratories Albuquerque, New Mexico 87115	Title Photovoltaic Projects Division
	Contract No. SI89-77-56
Principal Investigator Name: Donald G. Schueler Phone: (505) 264-4041	Period of Performance October 1, 1977-September 30, 1978
Work Location Albuquerque, New Mexico	Fiscal Year 1978 Funding \$1,780,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico 87185	Cumulative Funding \$1,780,000

Summary

The general objective of this project was to plan, organize, and manage a program to analyze and provide conceptual, preliminary, and detailed designs of photovoltaic electric power systems. The specific objectives of this project were: (1) to provide conceptual photovoltaic power systems designs and evolve preferred systems configurations, preliminary design specifications, and detailed system designs and specifications for terrestrial applications in support of the field test and applications projects; (2) to analyze detailed photovoltaic power system performance characteristics and identify specific subsystem requirements; (3) to investigate significant photovoltaic power system cost reduction by the application of sunlight tracking and concentration, and develop the necessary technology and hardware to provide prototype subsystems; and (4) to define the requirements for photovoltaic energy storage and power conditioning subsystems. This project was to be performed primarily under competitive solicitations and contracts generated by Sandia Laboratories. The above funding provided for the Sandia project management and in-house technical work.

ELEMENT: System Definition and Development

Prime Contractor and Address Westinghouse, Aerospace Elec. Division P.O. Box 989 Lima, Ohio 45802	Title Design and Construction of a 40 to 50 kVa Power Conditioning Unit for PV Power Systems
	Contract No. Sandia 07-6940
Principal Investigator Name: Frank C. Stump Phone: (419) 224-4197	Period of Performance December 1, 1977-March 31, 1979
	Fiscal Year 1978 Funding \$232,000
Work Location Lima, Ohio	Cumulative Funding \$264,000
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico	

Summary

The objective of this project is to obtain the design, construction, bench test, and delivery of one production prototype 40 to 50 kVa power conditioning unit for incorporation in a photovoltaic power system. The power conditioning unit will consist of a DC-to-AC inverter and an associated power system controller. The unit will have three modes of operation: (1) in parallel with the standard 208 Vac, three-phase commercial utility service with maximum power extraction from the array, (2) stand-alone operation providing power to on-site loads up to array capacity, and (3) operation with on-site energy storage. The design of the PCU will lend itself to economical mass production and the contractor has the capability to manufacture the units on a production basis.

ELEMENT: System Definition and Development

Prime Contractor and Address Woodward-Clyde Consultants Three Embarcadero Center San Francisco, California 94111	Title Decision Analysis Methodology for PRDA-35
	Contract No. Sandia 07-7052
Principal Investigator Name: Craig Kirkwood Phone: (415) 956-7070	Period of Performance November 1, 1977-March 15, 1978
Work Location San Francisco, California	Fiscal Year 1978 Funding \$63,100
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico 87185	Cumulative Funding \$63,100

Summary

The objective of this contract was the provision of a decision analysis methodology, including the appropriate attributes, weightings, and tradeoff factors, to be used to evaluate and rank order proposals for the implementation of photovoltaic concentrator experiments. Also provided was a methodology for selecting a portfolio of proposals to give programmatic diversity. This methodology is capable of testing the sensitivity of the rank order by varying the weighting of the various criteria.

ELEMENT: System Definition and Development

Prime Contractor and Address Woodward-Clyde Consultants Three Embarcadero Center San Francisco, California 94111	Title Decision Analysis Methodology for PRDA-38
Principal Investigator Name: Alan Sickerman Phone: (415) 956-7070	Contract No. Sandia 13-0238
Work Location San Francisco, California	Period of Performance April 14, 1978-July 14, 1978
Government Technical Representative and Address Sandia Laboratories Albuquerque, New Mexico 87185	Fiscal Year 1978 Funding \$50,000
	Cumulative Funding \$50,000

Summary

The purpose of this contract was to review the list of attributes and scales developed by Sandia for the PRDA-35 selection process and make appropriate changes. The technical worth evaluation code was modified to accommodate the new utility and weighting functions. The portfolio selection code was streamlined and several new options were incorporated into this code.

System Application Experiments

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ELEMENT: System Application Experiments

Prime Contractor and Address Abacus Controls, Inc. P.O. Box 893 Somerville, New Jersey 08876	Title Production Prototype Inverter for Photovoltaic Applications
	Contract No. EX 76A-29-1022 NAS3-20607
Principal Investigator Name: George O'Sullivan Phone: (201) 526-6010	Period of Performance March 1, 1977-September 30, 1978
Work Location Somerville, New Jersey	Fiscal Year 1978 Funding \$67,500
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$128,800
Summary	

The objective of this work was to design, test, and fabricate a 10 kVA self-commutated inverter to be used in photovoltaic power system tests.

A conceptual design was provided by the contractor. Based on this design an inverter was fabricated and recently delivered for acceptance testing.

ELEMENT: System Application Experiments

Prime Contractor and Address Acurex Corporation 485 Clyde Avenue Mountain View, California 94042	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-4280
Principal Investigator Name: F. Moreno Phone: (415) 964-3200	Period of Performance June 1, 1978-February 28, 1979
Work Location Mountain View, California	Fiscal Year 1978 Funding \$494,700
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$494,700

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

Acurex selected G.N. Wilcox Memorial Hospital in Kauai, Hawaii, for their experiment. The system will supply 100 kW peak electrical power to handle part of the hospital's a.c. load. The concentrator, designed by Acurex, is a 100X, hermetically sealed, reflective glass dish that uses sealed-beam headlamp technology. The silicon cells are water-cooled, and the heat removed is used to supply part of the hospital's hot water. Hospital air conditioning and hot-water heating loads peak at midday and in the summer, providing a good match with solar availability at the 22° latitude. Hawaii, which is strongly dependent on expensive imported fuels, could be an early commercial market for photovoltaic systems.

ELEMENT: System Application Experiments

Prime Contractor and Address Arizona Public Service Co. 411 North Central Avenue Phoenix, Arizona 85036	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-5317
Principal Investigator Name: Eric Weber Phone: (602) 271-2194	Period of Performance June 1, 1978-February 1979
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$461,500
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$461,500

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The Arizona Public Service Company, an electric utility, will design a 500-kW peak electric system for installation at the Phoenix Sky Harbor International Airport. The system, which will be tied directly to the utility's power grid in its primary operational mode, can be connected to an isolated load center in the airport terminal as an alternate operational mode. System size is large enough to be treated as a power generating plant on the grid-system by utility dispatch. A major subcontractor in this project is the Motorola Government Electronics Division for system and array design. The concentrator will be Motorola's 70X cassegrainian module which utilizes passively cooled silicon cells.

ELEMENT: System Application Experiments

Prime Contractor and Address Arizona State University Office of Research Grants and Contracts Tempe, Arizona 85281	Title Study of the Social and Economic Impact of PV Power on the Papago Indian Village of Schuchuli, AZ
Principal Investigator Name: Dr. Donald M. Bahr Phone: (602) 965-5913	Contract No. EX-76-A-29-1022 DEN 3-50 Period of Performance July 10, 1978-November 10, 1979
Work Location Schuchuli, Arizona	Fiscal Year 1978 Funding \$16,100
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$16,190

Summary.

The objective of this effort is to determine the significant social and economic effects of introducing a solar cell power system into the Indian village of Schuchuli, Arizona.

The contractor shall study and document the factors which characterize the village prior to initial operation of the solar cell system and the impact of the solar cell power system on the domestic and communal activities within the village.

The result shall be a report including data, analysis, and interpretations as well as recommendations and conclusions.

ELEMENT: System Application Experiments

Prime Contractor and Address Battelle Corporation Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: Don Carmichael Phone: (614) 424-6424	Contract No. ET-78-C-04-4267 Period of Performance June 1, 1978-February 28, 1979
Work Location Columbus, Ohio 43201	Fiscal Year 1978 Funding \$356,900
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$356,900

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The preliminary conceptual design for the Battelle Columbus Laboratories' experiment is to supply a peak output of 150 kW to an office-maintenance building in Columbus, Ohio. The photovoltaic array, designed by Spectrolab, will utilize 20X reflective parabolic troughs mounted on two-axis steerable turntables. The array will be located on a site owned by Columbus and Southern Ohio Electric Company next to the primary experiment load. Several modes of operation will be evaluated, including single-load operation, load-center operation (multibuilding load) with and without onsite storage, excess power feed to the utility grid, and parallel operation with the utility source. Nontechnical issues to be addressed include utility rate structure impacts and grid-feedback credits.

ELEMENT: System Application Experiments

Prime Contractor and Address BDM Corporation 2600 Yale Boulevard, S.E. Albuquerque, New Mexico 87106	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: Wayne Kauttman Phone: (505) 843-7870	Contract No. ET-78-C-04-5313
Work Location Albuquerque, New Mexico	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$342,200
	Cumulative Funding \$342,200
Summary	

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The BDM Corporation plans to design and install a 50-kW system on their new headquarters building in Albuquerque, New Mexico. The system will supply at least 20 percent of the building's electrical load and the entire heating load from the heat collected by the active array cooling system. The collectors will be Solar Kinetic's one-axis tracking reflective trough, thermal collectors modified to accept a silicon-cell assembly receiver. The conceptual system design calls for half the array to be oriented east-west and half to be oriented north-south. This arrangement will provide a trade-off between the smaller seasonal output variation of the east-west array and the greater yearly energy generation of the north-south array. An optional mode of operation is to feed power back into the utility grid.

ELEMENT: System Application Experiments

Prime Contractor and Address Booz-Allen-Hamilton Design & Development Division 8801 E. Pleasant Valley Road Cleveland, Ohio 44131	Title Schuchuli Operational Manual
	Contract No. EX-76-A-29-1022 C-19795-D
Principal Investigator Name: Dr. William F. Hahn Alt: Kert Artwick Phone: (216) 524-5900	Period of Performance August 4, 1978-October 16, 1978
Work Location Cleveland, Ohio	Fiscal Year 1978 Funding \$9,900
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$9,900

Summary

The objective of this contract is to provide services, labor, and materials to write an operations manual for a photovoltaic village power system. The power system is to be installed in the Papago Indian Village of Schuchuli (Gunsight), Arizona. The three volume manual will consist of the following data:

- Volume I. Overall Orientation—General Description of System and Its Operation.
- Volume II. Operation and Maintenance.
- Volume III. System/Component Troubleshooting and Repair.

ELEMENT: System Application Experiments

Prime Contractor and Address Carr Liggett Advertising, Inc. 815 Superior Avenue Cleveland, Ohio 44114	Title Press Releases, Technical Article and Dedication Ceremonies
	Contract No. EX-76-A-29-1022 DEN 3-45
Principal Investigator Name: John H. Haselow Phone: (216) 696-0330	Period of Performance March 3, 1978-November 1978
	Fiscal Year 1978 Funding \$42,000
Work Location Cleveland, Ohio	Cumulative Funding \$42,000
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	

Summary

The object of this contract is to supply the necessary materials and manpower for press releases, technical articles, and dedication ceremonies on three experimental solar cell powered systems at: (1) a forest lookout tower in Lassen National Forest, California; (2) Papago Village Power Project at Schuchuli, Arizona; and (3) an air pollution monitor in Liberty Park, New Jersey.

This is being accomplished through liaison between the media and appropriate Government agencies.

The result is to draw national attention to these new experiments using solar cell power.

ELEMENT: System Application Experiments

Prime Contractor and Address Department of Defense US Army Mobility Equipment Research and Development Command Ft. Belvoir, Virginia 20060	Title Military Applications of Photovoltaic Systems
Principal Investigator Name: Mr. Donald D. Faehn Phone: (703) 664-3663	Contract No. Interagency Agreement EG-76-A-29-1031 Period of Performance September 1975-December 31, 1978
Work Location Ft. Belvoir, Virginia	Fiscal Year 1978 Funding \$200,000
Government Technical Representative and Address US Army MERADCOM Ft. Belvoir, Virginia 22060	Cumulative Funding \$1,892,236

Summary

The objective of this project is to complete the construction on six solar cell power systems for candidate military applications. FY 78 effort is concentrated on the 60 kW Solid State Inverter/Solar Cell Array. In addition, the smaller demonstration items are being evaluated in representative military environments.

Six projects were selected to cover a broad range of power, voltage, and duty requirements. Five projects form the basis of the demonstration program. Design and construction of the initial five demonstration projects began in November 1975. These five projects required a 30 kW allocation of solar cell modules from the 46 kW block which was procured by JPL for DOE's test and demonstration program in early 1976. The five projects and their characteristics are listed below:

<u>Project</u>	<u>Peak Watts</u>	<u>Nominal Voltage</u>	<u>Demonstration Site</u>
a. Small Battery Charger	150	20V	Ft. Belvoir & Field
b. Radio Relay A.	35	24V	Ft. Belvoir & Field
B.	74	12V	Ft. Belvoir & Field
c. Telephone Central Ofc	2400	48V	Ft. Belvoir, Ft. Hood,
			Patrick AFB
d. Water Purification Plant	10800	240V	Ft. Belvoir
e. Remote Radar	12000	120/208V	China Lake, CA

Responses by the many military personnel and other visitors to the demonstration indicate that the program was successful in promoting an awareness of solar photovoltaic systems as an attractive alternative source of electric power for military equipment.

ELEMENT: System Application Experiments

Prime Contractor and Address Delta Electronic Control Corp. 2801 South Main Street Irvine, California 92714	Title 60 Kilowatt Solid State Inverter/Solar Cell Array
Principal Investigator Name: Mr. Dietrich J. Roesler Phone: (703) 664-3663	Contract No. DAAK-70-78-C-0018 Period of Performance September 1, 1977-January 1, 1979
Work Location Irvine, California	Fiscal Year 1978 Funding \$285,650
Government Technical Representative and Address US Army MERADCOM Ft. Belvoir, Virginia 22060	Cumulative Funding \$285,650

Summary

The primary objective of the 60 kW solar cell power system is to demonstrate that a dc-ac photovoltaic energy conversion system without energy storage can effectively augment a remote military power network. The demonstration is hardware oriented and it will uncover the extent to which a photovoltaic system can provide reliable power with subsequent savings in fuel. In addition, it will identify requirements in system operation, maintenance, and personnel training and will provide operational cost data. These are not generally available from analytic studies.

The 60 kW solar cell power system will be installed at the Mt. Laguna Air Force Station in California. It will augment an existing diesel power plant with an average load of about 750 kW. The diesel power plant has a total capacity of 2050 kW; they have six diesel generators rated at 300 kW each and one diesel generator rated at 250 kW. Three of the generators run continuously for 24 hours per day, seven days per week. The solar cell power plant can generate up to 10 percent of the average load of the diesel power plant and it is anticipated that an equivalent amount of fuel can be saved. The solar cell power system consists of a solar cell array, a paralleling and monitoring panel, measuring and monitoring instruments, control and protection devices, interconnecting cables and a dc to ac inverter. The inverter is connected by cables to the diesel generator power plant. In this configuration, the power plant will provide for high motor-starting currents and back-up power.

The program is generally on schedule. Design and fabrication of the main components of the system have been completed. Environmental assessment has been accomplished. Checkout of the inverter and the monitoring panel has been initiated. The site construction was started on September 1, 1978. System turn on is planned for February 1979 with dedication in April 1979.

ELEMENT: System Application Experiments

Prime Contractor and Address Desert Sunshine Exposure Tests, Inc. Box 185, Black Canyon Stage Phoenix, Arizona 85020	Title Exposure Tests
Principal Investigator Name: Gene Zerlaut Phone: (602) 465-7525	Contract No. EX-76-A-29-1022 NAS3-20721
	Period of Performance January 1, 1977-April 1, 1978
Work Location Phoenix, Arizona	Fiscal Year 1978 Funding \$6,000
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$63,600

Summary

The objective of this work was to rent several of Desert Sunshine Exposure Tests' standard solar test machines for solar cell module material exposure to concentrated sunlight, and to modify three machines for special test purposes.

The approach used was to test the solar cell materials on an equatorial mount with mirrors to provide accelerated test conditions. The results of this material testing was reported.

ELEMENT: System Application Experiments

Prime Contractor and Address DIKU, Inc. 8141 Tyler Blvd. Mentor, Ohio 44060	Title Solar Cell Module Inspection and Testing
	Contract No. EX-76-A-29-1022 DEN 3-5
Principal Investigator Name: C. Masielli Phone: (216) 951-9660	Period of Performance September 22, 1977-September 21, 1978
	Fiscal Year 1978 Funding \$0
Work Location Mentor, Ohio	Cumulative Funding \$36,000
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	

Summary

The object of this work has been to receive, process, and inventory solar cell modules for Lewis Research Center applications from Jet Propulsion Laboratory procurements.

The contractor received, stored, made I-V and spectral response curves for, recorded, and shipped solar cell modules made by the various manufacturers.

This contract relieved Lewis Research Center from performing these routine functions in-house.

ELEMENT: System Application Experiments

Prime Contractor and Address E-Systems, Inc. Energy Technology Center P.O. Box 6118 Dallas, Texas 75222	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-5311
Principal Investigator Name: Mark O'Neill Phone: (214) 272-0515	Period of Performance June 1, 1978-February 1979
Work Location Dallas, Texas	Fiscal Year 1978 Funding \$282,400
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$282,400

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

E-Systems will use their linear Fresnel lens concentrator with a concentration ratio of 25X in conjunction with silicon solar cells to generate 20 kWe and 146.5 kWt. This energy will be supplied to the central utility plant at the Dallas-Ft. Worth airport. Electricity from the array will be used by small motors and lights within the plant. Heat from the solar array will preheat boiler feedwater for the steam plant. The feedwater is relatively cool, so that the solar cells will stay at a low mean temperature (55°C) and hence have a relatively high conversion efficiency. About 60 percent of the available annual direct normal insolation will be effectively delivered to the plant as useful electrical and thermal energy.

ELEMENT: System Application Experiments

Prime Contractor and Address Energy Analysis, Inc. 12160 Claretta Street Lake View Terrace, California 91342	Title Low Power Terrestrial Photovoltaic System Design Information Reference
	Contract No. EX-76-A-29-1022 DEN 3-24
Principal Investigator Name: Frederick T.C. Bartels Phone: (213) 899-1535	Period of Performance February 22, 1978-August 22, 1978
	Fiscal Year 1978 Funding \$32,818
Work Location Lake View Terrace, California	Cumulative Funding \$32,618
Government Technical Representative and Address NASA Lewis Research Center Cleveland, Ohio 44135	

Summary

The object of this work has been to prepare a reference handbook, for use by applications engineers using hand-held computers, containing information to configure and design terrestrial PV systems under 10 kWp in size.

The reference was prepared in the format of an engineering handbook and contained data on PV system component characteristics, system design methods, insolation tables, array sizing and tilt, battery storage, power conditioning, and control.

ELEMENT: System Application Experiments

Prime Contractor and Address General Electric Company Space Systems Operations P.O. Box 8661 Philadelphia, Pennsylvania 19101	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: A. Kirpich Phone: (215) 962-4285	Contract No. ET-78-C-04-5314
Work Location Philadelphia, Pennsylvania	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$599,500
	Cumulative Funding \$599,500

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The General Electric design will provide 305 kW peak electric power to a constant load for pumping water for the marine exhibits at Sea World in Orlando, Florida. The photovoltaic collectors, providing a concentration ratio of 34X, are General Electric's recently designed, two-axis tracking, turntable-mounted, parabolic troughs. The silicon cells are water-cooled. More than 12 million visitors annually visit Orlando, giving this project high public visibility. Special displays and educational programs provided by Sea World will further enhance this visibility.

ELEMENT: System Application Experiments

Prime Contractor and Address InterTech Solar Corporation 100 Main Street Warrenton, Virginia 22186	Title Array Structure Design Reference for Low-Power PV Applications (up to 10 kW)
Principal Investigator Name: Dr. H.S. Liers Phone: (703) 347-7900	Contract No. EX-76-A-29-1022 DEN 3-33 Period of Performance March 6, 1978-November 5, 1978
Work Location Warrenton, Virginia	Fiscal Year 1978 Funding \$40,697
Government Technical Representative and Address NASA Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$40,697

Summary

The object of this work is to prepare a reference handbook, for use by applications engineers using hand-held computers, detailing module, panel, and array structural requirements for PV systems under 10 kWp in size. The reference will also identify typical support structural arrangements appropriate to categories of applications such as remote instrument platforms, water pumping and village power installations. Pertinent data will be provided on the trade-offs between various sizes, shapes, and connections to minimize capital cost and enhance maintainability.

ELEMENT: System Application Experiments

Prime Contractor and Address InterTech Solar Corporation 100 Main Street Warrenton, Virginia 22186	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-4290
Principal Investigator Name: Dr. H.S. Liers Phone: (703)-347-7900	Period of Performance June 1, 1978-February 28, 1979
	Fiscal Year 1978 Funding \$265,000
Work Location Warrenton, Virginia	Cumulative Funding \$265,000
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The Fauquier High School in Warrenton, Virginia, will be the site for a 20-kW electrical system being designed by InterTech Solar. The photovoltaic concentrator system will be placed next to the existing solar thermal system designed and built by InterTech Solar in 1974. The primary concentrator will be the Acurex parabolic trough designed for thermal applications and modified for photovoltaics. The Del thermal concentrator will be retained in the early design stages as an alternate collector. The cells will be actively cooled, but no use is planned for the thermal energy.

ELEMENT: System Application Experiments

Prime Contractor and Address Kaman Sciences Corporation 1500 Garden of the Gods Road P.O. Box 7463 Colorado Springs, Colorado 80933	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: Douglas Jardine Phone: (303) 599-1931	Contract No. ET-78-C-04-4278
Work Location Colorado Springs, Colorado	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$370,000
	Cumulative Funding \$370,000

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

Electrical and thermal needs of Kaman Sciences computing center and manufacturing plant are the loads for this application. The array, sized at 64 kWe, is composed of heliostat-type ground-mounted concentrators and roof-mounted solar axis concentrators. These concentrators are designed by ARCO Solar and Northrop, respectively, and use Fresnel lenses with a concentration ratio of 32X. The systems will receive, condition, control, store, convert, and dispatch the electricity and heat in several operational modes. In particular, Colorado Springs City Utility and Public Service Company of Colorado will extensively study various utility rate structures.

ELEMENT: System Application Experiments

Prime Contractor and Address City of Los Angeles Department of Water and Power P.O. Box III Los Angeles, California 90051	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: Frank Goodman Phone: (213) 481-8675	Contract No. ET-78-C-04-4281
Work Location Los Angeles, California	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operation Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$226,200
	Cumulative Funding \$226,200

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The Los Angeles Department of Water and Power plans to connect their system to an electric motor load and the electric utility grid at their Sun Valley generating station near Los Angeles. Provisions will be made to supply the motor load with power from the array or the utility system. When the motor load demand is low, the photovoltaic system will deliver excess power to the utility grid. Spectrolab will provide the 200-kW photovoltaic array, a 20X turntable-mounted parabolic-trough design.

ELEMENT: System Application Experiments

Prime Contractor and Address Martin Marietta Corporation Denver Division Box 179 Denver, Colorado 80201	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-5312
Principal Investigator Name: Dick Donovan Phone: (303) 973-4658	Period of Performance June 1, 1978-February 28, 1979
Work Location Denver, Colorado	Fiscal Year 1978 Funding \$303,300
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$303,300

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The Roxborough State Park Visitors Center, 25 miles south of Denver, Colorado, is the site of the Martin-Marietta experiment. This project intends to make the Visitors Center completely energy-independent by combining the photovoltaic array with the already-existing active and passive solar heating and cooling system. The concentrator system is based on Martin Marietta's existing Fresnel lens concentrator array design with a concentration ratio of 40X. The overall electrical system size is 68 kW.

ELEMENT: System Application Experiments

Prime Contractor and Address Motorola, Inc. Semiconductor Group 5005 East McDowell Road Phoenix, Arizona 85008	Title Market Definition Studies for PV Village Power Applications
Principal Investigator Name: Clyde Ragsdale Phone: (602) 244-3796	Contract No. EX-76-A-29-1022 DEN 3-49
Work Location Phoenix, Arizona	Period of Performance July 19, 1978-February 18, 1979
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Fiscal Year 1978 Funding \$50,000
	Cumulative Funding \$50,000

Summary

The object of this project is to identify the opportunities in the U.S. and its possessions for photovoltaics in the village power application market.

The approach is to conduct a thorough search of available published data on the market and to conduct appropriate personal and telephone interviews.

As a result, the contractor shall establish a market data base and do a detailed study on three selected applications.

ELEMENT: System Application Experiments

Prime Contractor and Address NASA Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135	Title Photovoltaic Tests and Applications Project
	Contract No. EX-76-A-29-1022
Principal Investigator Name: Roger S. Palmer Phone: (216) 433-4000 x6840	Period of Performance June 4, 1975-September 30, 1978
Work Location Cleveland, Ohio	Fiscal Year 1978 Funding \$1,600,000
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$6,991,700

Summary

The objectives of this project were: (1) to stimulate near-term markets for cost effective applications of photovoltaic systems; (2) to determine operating characteristics for a variety of solar cell systems and subsystems; (3) to devise and implement the methodology, techniques, and equipment to make accurate and reproducible measurements of solar cell and array performance, and diagnostic measurements on solar cells, modules and arrays; (4) to determine the endurance of solar cell modules, component parts, and their materials under environmental conditions for their intended use. To date, several photovoltaic systems (six remote weather stations, a highway dust warning sign, four insect survey traps, two refrigerators, two forest lookouts, and a water cooler at a visitors center) are operational. A photovoltaic village power system for the Papago Indian village at Schuchuli, Arizona, is under construction. Expansion of the National Systems Test Facility to 30 kW is underway. Market assessment studies on photovoltaic highway and village power applications are being completed along with handbooks on photovoltaic system design and array structure design.

This is a continuing project to which other photovoltaic applications will be added. The above funding provides for project management and in-house technical work as well as competitive solicitations and contracts.

ELEMENT: System Application Experiments

Prime Contractor and Address National Bureau of Standards Washington, D.C. 20234	Title Investigation of Techniques for Measuring the Absolute Spectral Response of Solar Cells
	Contract No. EX-76-A-29-1022 C-80668-C
Principal Investigator Name: Jon Geist Phone: (301) 921-2191	Period of Performance January 20, 1976-June 8, 1978
Work Location Gaithersburg, Maryland	Fiscal Year 1978 Funding \$0
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$20,000

Summary

The objective of the National Bureau of Standards has been to characterize solar cells by their absolute spectral response (milliampere short-circuit current output per milliwatts/cm² irradiance input for small wavelength intervals over the wavelength range from 0.3 to 1.2 μ m).

The contractors were to improve techniques for absolute spectral response measurements using amplitude-stabilized, laser radiation.

An international comparison of measured cells at about six wavelengths from about 350 nm to 850 nm and at 1.06 μ m was made.

ELEMENT: System Application Experiments

Prime Contractor and Address Naval Weapons Support Center Crane, Indiana 47522	Title Tropical Testing
	Contract No. EX-76-A-29-1022 C-1892-D
Principal Investigator Name: Kevin L. Holloway Phone: (812) 854-1430	Period of Performance February 7, 1977-September 29, 1978
Work Location Crane, Indiana	Fiscal Year 1978 Funding \$5,000
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$40,000

Summary

The objective of this work has been to perform accelerated endurance tests on Block II solar cell modules under simulated environments.

The results of exposure to rain and icing, sand and dust, temperature and humidity, vacuum steam pressure, fungus, temperature/altitude, thermal shock and salt fog will be monitored and documented in a final report.

ELEMENT: System Application Experiments

Prime Contractor and Address Commonwealth of Puerto Rico Office of the Governor P.O. Box 41089 Minillas Stn. Santurce, Puerto Rico 00940	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-4270
Principal Investigator Name: Frank Castellon Phone:	Period of Performance June 1, 1978-February 28, 1979
	Fiscal Year 1978 Funding \$499,900
Work Location Santurce, Puerto Rico	Cumulative Funding \$499,900
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The Energy Office of the Commonwealth of Puerto Rico has chosen a load center application consisting of two research buildings on the San Juan campus of the University of Puerto Rico. The primary load is the Center of Energy and Environment Research, with a peak electrical demand of 84 kW. The proposed system size is 150-kW peak; surplus generated electrical energy will be supplied to the Cancer Research Hospital. The concentrating collector is an existing 24X slat-reflector, thermal system designed by AAI Corporation and modified with a 1.7X secondary concentrator to give an overall concentration ratio of 40X. The projected energy collection of 1500 kWt will supply the heating needs of the load center.

ELEMENT: System Application Experiments

Prime Contractor and Address Research Triangle Institute P.O. Box 12194 Research Triangle Park, North Carolina 27709	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: R. M. Burger Phone: (919) 541-6928	Contract No. ET-78-C-04-4268
Work Location Research Triangle Park, North Carolina	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$307,800
	Cumulative Funding \$307,800

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

Research Triangle Institute (RTI) is designing a concentrator system to provide part of the electrical energy requirements for their new laboratory-office building at Research Triangle Park, N. C. The system size, a design option, will range from 90 to 300 kW. Most of the building load will be direct current so that inversion to ac will be required for little, if any, of the solar-supplied power. The photovoltaic collectors will consist of Motorola's two-axis tracking paraboloid concentrators with a concentration ratio of 70X. The Cassegrainian design of these concentrators offers the alternative of increasing the concentration ratio; this allows the incorporation of solar cells with higher conversion efficiencies than silicon, such as the mutli-bandgap cells under development at RTI.

ELEMENT: System Application Experiments

Prime Contractor and Address Solarex Corporation 1335 Piccard Drive Rockville, Maryland 20850	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-5310
Principal Investigator Name: Zim Putney Phone: (301) 948-0202	Period of Performance June 1, 1978-February 28, 1979
	Fiscal Year 1978 Funding \$319,800
Work Location Rockville, Maryland	Cumulative Funding \$319,800
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The solar cell production line at Solarex's facility in Rockville, Maryland, was chosen as the load for the Solarex experiment. The 200-kW photovoltaic array, which is actively cooled, will provide all the electrical and thermal energy needs of the production line. The array utilizes 40X parabolic troughs with two-axis tracking. In addition to the "solar-breeder" aspect of this experiment, technical and managerial practices that maximize the energy efficiency of the production operations (e.g., scheduling energy-intensive process steps for hours of peak insolation and use of "floating holidays" to reduce energy demand during extended periods of low insolation) will be introduced.

ELEMENT: System Application Experiments

Prime Contractor and Address Spectrolab, Inc. 2500 Gladstone Avenue Sylmar, California 91342	Title Pulsed Solar Simulator
Principal Investigator Name: Vincent DeLeo Phone: (213) 365-4611	Contract No. EX-76-A-29-1022 NAS3-20753
	Period of Performance March 9, 1977-December 29, 1977
	Fiscal Year 1978 Funding \$0
Work Location Sylmar, California	Cumulative Funding \$81,508
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	

Summary

The purpose of this contract was to build a pulsed solar simulator complete with data acquisition system to be used in calibrating and testing solar cells and panels.

ELEMENT: System Application Experiments

Prime Contractor and Address Sun Trac Corporation 1674 South Wolf Road Wheeling, Illinois 60090	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: Doug Moeller Phone: (312) 541-2095	Contract No. ET-78-C-04-4282
Work Location Wheeling, Illinois	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$176,800
	Cumulative Funding \$176,800

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

Sun Trac Corporation selected an industrial lighting application. The site, an industrial plant operated by the Area Lighting Division of the McGraw-Edison Company, is located in Racine, Wisconsin. Sun Trac will utilize their unique bubble-enclosed modules with two-dimensional compound parabolic concentrators, giving a concentration ratio of 70X on 0.64 inch diameter silicon cells. In the 50-kW experiment, Sun Trac will investigate the impact of photovoltaic systems on time-of-day rates for industrial plants with one-shift daytime operations. McGraw-Edison, site owner and active participant in the system design, will investigate special luminaire and ballast design for photovoltaic lighting applications.

ELEMENT: System Application Experiments

Prime Contractor and Address Technical Marketing Associates, Inc. 2250 Main Street Concord, Massachusetts 01742	Title Market Definition Study for Highway Applications
	Contract No. EX-76-A-29-1022 DEN 3-40
Principal Investigator Name: David W. Brown (President) Phone: (617) 369-5500	Period of Performance May 3, 1978-August 2, 1978
Work Location Concord, Massachusetts	Fiscal Year 1978 Funding \$49,147
Government Technical Representative and Address: NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$49,147

Summary

The objective of this work was to identify major opportunities for photovoltaics in the highway application market.

To achieve this objective, the contractor conducted a thorough search of available published data and in-depth personal and telephone interviews with manufacturers, suppliers, distributors, government agencies, end users, and trade associations.

A market data base was established, including two detailed applications studies.

ELEMENT: System Application Experiments

Prime Contractor and Address Center for Energy Research Texas Technical University Lubbock, Texas 79409	Title Photovoltaic Concentrator Application Experiment
Principal Investigator Name: William Marcy Phone: (806) 742-3543	Contract No. ET-78-C-04-4269
Work Location Lubbock, Texas	Period of Performance June 1, 1978-February 28, 1979
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Fiscal Year 1978 Funding \$433,700
	Cumulative Funding \$433,700

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

Texas Tech is planning an agricultural experiment involving deep-well irrigation in the trans-Pecos region of Texas. The site selected is representative of the deep-well irrigation problems of an agricultural region severely impacted by high energy costs. A 200-kW array will supply power in parallel with the utility grid to drive a 200-hp, three-phase pump motor to provide a lift of 540 feet. The collectors will be Honeywell's double-parabolic, two-axis tracking thermal design modified for photovoltaics.

ELEMENT: System Application Experiments

Prime Contractor and Address Tracor Northern, Inc. 2551 West Beltline Highway Middletown, Wisconsin 53562	Title Optical Multichannel Analyzer System
Principal Investigator Name: Don E. Osten Phone: (608) 831-6511	Contract No. EX-76-A-29-1022 DEN 3-3
	Period of Performance November 4, 1977-February 9, 1978
Work Location Middletown, Wisconsin	Fiscal Year 1978 Funding \$27,102
Government Technical Representative and Address NASA, Lewis Research Center Cleveland, Ohio 44135	Cumulative Funding \$27,102

Summary

The objective of this contract was to obtain a custom-built optical multichannel analyzer system. The system was needed to study total and diffuse sky irradiance of solar cells as well as their response to other light sources such as solar simulators.

ELEMENT: System Application Experiments

Prime Contractor and Address Varian Associates, Inc. 611 Hansen Way Palo Alto, California 94303	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-5315
Principal Investigator Name: Henri Maget Phone: (415) 493-4000	Period of Performance June 1, 1978-February 28, 1979
Work Location Palo Alto, California	Fiscal Year 1978 Funding \$560,000
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$560,000

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The Varian experiment represents the only gallium arsenide cell array. Fresnel lenses will provide a 500X concentration ratio for the gallium arsenide cells. The system will supply power to a utility substation in San Ramon, California, owned by the Pacific Gas and Electric Company. Experiment size, between 20 and 50 kW, will incorporate minor battery storage. The system is actively cooled. Possible uses of the thermal energy will be investigated; however, no thermal loads have yet been identified.

ELEMENT: System Application Experiments

Prime Contractor and Address Westinghouse Electric Corporation 1310 Beulah Road Pittsburgh, Pennsylvania 15235	Title Photovoltaic Concentrator Application Experiment
	Contract No. ET-78-C-04-4277
Principal Investigator Name: Paul P. Horan Phone: (412) 256-7802	Period of Performance June 1, 1978-February 28, 1979
Work Location Pittsburgh, Pennsylvania	Fiscal Year 1978 Funding \$342,000
Government Technical Representative and Address Ethan A. Walker DOE/Albuquerque Operations Office Albuquerque, New Mexico 87115	Cumulative Funding \$342,000

Summary

This contract is one of 17 projects for a Phase I design study of a photovoltaic concentrator application. Several of these 17 projects will be selected for Phase II system fabrication and installation and Phase III system operation. The purpose is to gain practical experience in operating PV concentrator on-site equipment.

The application to be served by the Westinghouse design is a local operating headquarters of the Georgia Power Company in Fulton County, Georgia. A 20X linear Fresnel lens concentrator array being designed by Westinghouse will be used in the application to provide 50 to 60 kW of peak electric power. Various modes of operation, including utility-grid operation, will be investigated.

Standards and Performance Criteria

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ELEMENT: Standards and Performance Criteria Projects

Prime Contractor and Address MIT-Lincoln Laboratory P.O. Box 73 Lexington, Massachusetts 02173	Title Photovoltaics Interim Performance Criteria and Test Methodology
	Contract No. XD-8-0958-1
Principal Investigator Name: Dr. Steve Forman Phone: (617) 862-5500	Period of Performance April 1, 1978-September 30, 1978
Work Location Lexington, Massachusetts	Fiscal Year 1978 Funding \$24,700
Government Technical Representative and Address SERI 1536 Cole Blvd. Golden, Colorado 80401	Cumulative Funding \$24,700

Summary

The objective of this project was to develop interim performance criteria (IPC) and test methodology for photovoltaics.

The approach used in this program was to develop the IPC and test methodology through a management system consisting of a Coordinating Council and its hierarchy.

The Council identified needs and priorities, and established time frames as appropriate for development.

In this activity, membership and participation in Coordinating Council activities was a key element leading to the development of the criteria and of the test methodology. An element of the participation was the leadership of a task group which addressed technical development of draft test methodology for power conditioning and control, cabling, and storage.

ELEMENT: Standards and Performance Criteria Projects

Prime Contractor and Address National Bureau of Standards Washington, D.C. 20234	Title Photovoltaic Interim Performance Criteria and Test Methodology
	Contract No. XD-8-0959-1
Principal Investigator Name: Dr. Harry Schafft Phone: (301) 921-3625	Period of Performance June 5, 1978-September 30, 1978
Work Location Gaithersburg, Maryland	Fiscal Year 1978 Funding \$52,500
Government Technical Representative and Address SERI 1536 Cole Blvd. Golden, Colorado 80401	Cumulative Funding \$52,500
Summary	

The objective of this project has been to develop interim performance criteria (IPC) and test methodology for photovoltaics. The approach used in this program was to develop the IPC and test methodology through a management system consisting of a Coordinating Council and its hierarchy.

The Council identified needs, priorities, and established time frames as appropriate for development.

In this activity, research was used to identify extant standards, performance criteria, test methodology and reports pertinent to this photovoltaics program. In addition, liaison between the Solar Heating and Cooling of Buildings (SHACOB) standards community and the Coordinating Council was to be initiated and maintained to gather the benefits of the experience of the SHACOB standards activity.

In addition to maintaining membership and participating in Council Activities, chairing the subcommittee on Power Conditioning and Controls was a responsibility necessary to identify priorities and needs, and to lend support to the development of criteria and test methodology.

ELEMENT: Standards and Performance Criteria Projects

Prime Contractor and Address Solar Energy Research Institute Golden, Colorado 80401	Title Performance Criteria and Test Methodology for Photovoltaics
Principal Investigator Name: Steve Forman Phone: (617) 862-5500	Contract No. EY-76-C-02-4094 Period of Performance October 1, 1978-Open
Work Location Golden, Colorado	Fiscal Year 1978 Funding \$200,000
Government Technical Representative and Address Gary Nuss, SERI 1536 Cole Boulevard Golden, Colorado 80401	Cumulative Funding \$200,000

Summary

The objectives of this project are to develop photovoltaic performance criteria and test methodology to permit transfer to the voluntary consensus system for development as American National Standards. This activity will aid the commercialization of the photovoltaics technology by development of a common language for communication in the PV community, the promotion of consumer confidence, and aid in the development of a viable industry infrastructure.

The general approach is to utilize a management system consisting of a Coordinating Council and its hierarchy. The council identifies needs, establishes priorities, and supports the drafting of test methodology consistent with the overall objectives of the program. Since the project was initiated, substantial progress has been made leading to the anticipated publication of an Interim Performance Criteria and Test Methodology Document for Photovoltaics. A Coordinating Council was established in the second quarter of FY 78, with subsequent establishment of its hierarchical elements in the remainder of the fiscal year. Accomplishments include: (1) the development of terms and definitions for the photovoltaics subsystems hierarchy; (2) identification of needs and priorities for development; (3) research on extant related test methodology and standards; (4) support for the drafting of test methodology; and (5) development of an overall plan for this project.

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BIBLIOGRAPHY

This bibliography lists reports and papers which have resulted from or are related to research projects described in this Program Summary.

Most of the technical journals/publications containing listed papers can be obtained through technical libraries. All publication/reports in paragraph 3 and 4 having a SAND document number can be obtained from:

National Technical Information Service (NTIS)
5285 Port Royal Road
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For further information contact:

DOE's Photovoltaic Program
Division of Distributed Solar Technology
600 E. Street, N.W.
Washington, D.C. 20545
(202) 376-1957

Bibliography

1. The following publications and technical reports are related to the Program Assessment and Integration Projects described on pages 73-75.

"Photovoltaic Mission Analysis - Final Summary Report"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-07)-1
Date: August 1978

"Survey and Screening of Intermediate-Size Photovoltaic Total Energy and Electric Applications"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-02)-2
Date: August 1978

"Analysis of Photovoltaic Total Energy Systems for Single Family Residential Applications"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-02)-1
Date: August 1978

"Photovoltaic Central Power Plants - Some New Evaluations on the Basis of Revised Insolation Data"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-04)-3
Date: July 1978

"Pennies A Day - Financing Early Deployment of Photovoltaic Utility Applications Through A User Subsidy"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-04)-2
Date: May 1978

"Overview of Photovoltaic Market Studies"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-05)-1
Date: May 1978

"Photovoltaic Mission Analysis - Some Recent Results"

Author: The Aerospace Corporation
Report No.: ATR-78(7694-01)-1
Date: October 1977

"Mission Analysis of Photovoltaic Solar Energy Conversion," Volumes I-IV

Author: The Aerospace Corporation
Report No.: ATR-77(7574-07)-1
Date: March 1977

"Mission Analysis of Photovoltaic Solar Energy Systems," Final Report, Volumes I-III

Author: The Aerospace Corporation
Report No.: ATR-76(7476-01)-1
Date: December 1, 1975

"A Critical Review of Single Fuel and Interfaced Residential Energy Demand Models"

Author: R.S. Hartman

Report No.: MIT-EL-78-003

Date: March 1978

"Micro Irrigation with Photovoltaics"

Author: D.V. Smith

Report No.: MIT-EL-78-006

Date: April 1978

"An Economic Analysis of Grid-Connected Residential Solar Photovoltaic Power Systems"

Authors: P.R. Carpenter and G.A. Taylor

Report No.: MIT-EL-78007

Date: May 1978

"Optimal Search for the Best Alternative"

Author: M. Weitzman

Report No.: MIT-EL-78-008

Date: May 1978

"Methodology and Definition of Solar Photovoltaic Planning Regions"

Authors: R.D. Tabors and P.R. Carpenter

Report No.: MIT-EL-78-034

Date: July 1978

2. The following publications and technical reports are related to the Research and Advanced Development projects described on pages 77-126.

"Forward-Bias Capacitance and Current Measurements for Determining Lifetimes and Band Narrowing in P-N Junction Solar Cells"

Authors: A. Neugroschel, P.J. Chen, S.C. Pao, and F.A. Lindholm

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

"Recent Improvements in AMOS Solar Cells"

Authors: R.J. Stirn, Y.C.M. Yeh, E.Y. Wang, F.P. Ernest, and C.J. Wu

Publication: Technical Digest of the 1977 International Electron Devices Meeting, Washington, D.C.

Date: December 5-7, 1977

"Development of High-Efficiency GaAs Polycrystal Solar Cells"

Author: Rockwell International Science Center

Date: Quarterly Report January 23, 1978 to April 23, 1978

"The Properties of Homoepitaxial InP Films Prepared by the MO-CVD Process for the Fabrication of Heterojunction Solar Cells"

Authors: H.M. Manasevit, K.L. Hess, P.D. Daphus, R.P. Ruth, J.J. Yang, A.G. Campbell, R.E. Johnston, L.A. Moudy, R.H. Bube, L.B. Fabick, A.L. Fahrenbruch, and M-J. Tsai

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

3. The following publications and technical reports are related to the Technology Development Low-Cost Solar Array projects described on pages 128-225.

A. Published Papers Included in the Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference, June 1978

"A Candidate Low-Cost Processing Sequence for Terrestrial Silicon Solar Cell Panel"

Authors: D.B. Bickler, B.D. Gallagher, and L.E. Sanchez

"The Effects of Misfit Dislocations on the Photovoltaic Properties of CdS-Based Solar Cells"

Authors: K.A. Jones, C.H. Cheng, and B.F. Shirreffs

"Mechanisms of Photon-Induced Changes in Silicon Solar Cell Parameters"

Authors: L.J. Cheng, G.B. Turner, R.G. Downing, C.H. Wang, and C.H. Seaman

"Lifetime Cost and Performance Model for Photovoltaic Power Systems"

Author: C.S. Borden

"Photovoltaic Design Optimization for Terrestrial Applications"

Author: R.G. Ross, Jr.

"The Effects of Copper and Titanium on Silicon Solar Cells"

Author: A.M. Salama

"Environmental Qualification Testing of Terrestrial Solar Cell Modules"

Authors: A.R. Hoffman and R.G. Ross, Jr.

"Some Failure Modes and Analyses Techniques for Terrestrial Solar Cell Modules"

Authors: A. Shumka and K.H. Stern

"Ultra-Low-Mass Flexible Planar Solar Arrays Using 50-Micron-Thick Solar Cells"

Author: E.N. Costogoe

"Effect of Multiblade Slurry Saw Induced Damage on Silicon Solar Cells"

Authors: T. Daud, J.K. Liu, G.A. Pollock, and K.M. Koliwad

"Effect of Copper Impurity on Polycrystalline Silicon Solar Cells"

Authors: T. Daud and K.M. Koliwad

"Environmental Testing of Flat Plate Solar Cell Modules"

Authors: J. Griffith, L. Dumas, A. Hoffman

Publication: IES Solar Seminar on Testing Solar Energy Materials and Systems -May 1978

"Copper Precipitation Effects in Silicon Used in Solar Cells"

Author: A.M. Salama

Publication: Electrochemical Society Meeting - May 1978

"A Life Prediction Methodology for Encapsulated Solar Cells"

Author: C.D. Coulbert

Publication: Seminar on Testing Solar Materials and Systems - May 1978

B. The following Published Documents Prepared by the Jet Propulsion Laboratory's
Low-Cost Solar Array Data Center

"The Cost of Energy from Utility-Owned Solar Electric Systems"

Author: J.W. Doane

Report No.: 5040-29

Date: June 1976

"LSA First Quarterly Report - April 1976 to June 1976"

Author: Project Office

Report No.: 5101-7

"LSA Second Quarterly Report - July 1976 to September 1976"

Author: Project Office

Report No.: 5101-10

"Silicon Crystal Technology for Terrestrial Photovoltaic Solar Energy Conversion - Progress"

Author: J. Zoutendyk

Report No.: 5101-12

Date: October 28, 1976

"Availability of Ultraviolet Radiation Data for Encapsulation System Design"

Author: W. Carroll

Report No.: 5101-13

Date: February 14, 1977

"Industrial Growth and the Factors that Affect Growth Rate - Preliminary Analysis"

Author: E. Edelson

Report No.: 5101-14

Date: January 26, 1977

"SAMICS (Solar Array Manufacturing Industry Costing Standards) Workbook"

Author: R.G. Chamberlain

Report No.: 5101-15

Date: September 1977

"Block IV Solar Cell Module Design and Test Specification for Intermediate Load Center Applications"

Author: J. Arnett

Report No.: 5101-16, Revision A

Date: November 1, 1978

"Cyclic Pressure - Load Developmental Testing of Solar Panels"

Author: D. Moore
Report No.: 5101-19
Date: November 28, 1977

"Test Program on Low-Cost Connector for Solar-Array Modules"

Author: A. Cantu
Report No.: 5101-20
Date: February 28, 1977

"Rejection Criteria for JPL LSA Modules"

Authors: Bishop/Anhalt
Report No.: 5101-21 Revision B
Date: October 3, 1978

"Project Quarterly Report - 3 October 1976 to December 1976"

Author: LSA Project Office
Report No.: 5101-24

"Thermal Performance Testing Photovoltaic Modules"

Authors: J.W. Stultz and L.C. Wen
Report No.: 5101-31
Date: July 29, 1977

"Quarterly Report - January 1977 to March 1977"

Author: LSA Project Office
Report No.: 5101-32

"Price Estimation Guidelines, a Precursor Adjunct to SAMIS III"

Authors: Chamberlain/Aster
Report No.: 5101-33
Date: September 10, 1977

"User Handbook for Block II Silicon Solar Cell Modules"

Author: M. Smokler
Report No.: 5101-36
Date: October 15, 1977

"LSA Field Test Activity System Description"

Author: P. Jaffe
Report No.: 5101-39, JPL/LSA Data Center
Date: August 3, 1977

"Development and Validation of a Life-Prediction Methodology for ISSA Encapsulated Modules"

Author: C.D. Coulbert
Report No.: 5101-40, JPL/LSA Data Center

"Module Efficiency Definitions, Characteristics and Examples"

Author: R.A. Grippi

Report No.: 5101-43, JPL/LSA Data Center

Date: October 7, 1977

"SAMICS Input Data Preparation" (Solar Array Manufacturing Industry Costing Standards)

Author: R.G. Chamberlain

Report No.: 5101-44, JPL/LSA Data Center

Date: September 30, 1977

"Environmental Hail Model for Assessing Risk to Solar Collectors"

Authors: Gonzalez/Ross

Report No.: 5101-45, JPL/LSA Data Center

Date: December 6, 1977

LSA Fifth Quarterly Report

Author: Project Office

Report No.: 5101-46, JPL/LSA Data Center

Date: April to June 1977

"Chemical Vapor Deposition of Si from Silane Pyrolysis"

Authors: Praturi/Lutwack/Hsu

Report No.: 5101-51, JPL/LSA Data Center

Date: July 17, 1977

"Compatibility Studies of Various Refractory Materials in Contact with Molten Silicon"

Authors: "O'Donnell/Leipold/Hagan

Report No.: 5101-53, JPL/LSA Data Center

Date: March 1, 1978

"Historical Evidence of Importance to the Industrialization of Flat-Plate Silicon Photovoltaics": Executive Summary

Authors: J.L. Smith/Gates/Lee

Report No.: 5101-54 Volume I and II, JPL/LSA Data Center

Date: April 1978

"Structure of Deformed Silicon and Implications for Low-Cost Solar Cells"

Author: G.B. Turner

Report No.: 5101-56, JPL/LSA Data Center

Date: March 1, 1976

"Multi-Wire Slurry Wafering Demonstrations"

Author: C.P. Chen

Report No.: 5101-57, JPL/LSA Data Center

Date: February 22, 1978

"Measurement of Solar and Simulator Ultraviolet Spectral Irradiance"

Author: R.S. Estey

Report No.: 5101-58, JPL/LSA Data Center

Date: March 15, 1978

"SAMICS Usage Update No. 1"

Author: R.G. Chamberlain

Report No.: 5101-59, JPL/LSA Data Center

Date: February 1, 1978

"SAMICS Computer Program User's Guide-Release 1"

Author: M.A. Metcalf

Report No.: 5101-60, JPL/LSA Data Center

Date: March 24, 1978

"Encapsulation Material Trends Relative to 1986 Cost Goals"

Author: E. Cuddihy

Report No.: 5101-61, JPL/LSA Data Center

Date: April 13, 1978

"Photovoltaic Module Design, Qualification and Testing Specifications"

Author: R.G. Ross

Report No.: 5101-65, JPL/LSA Data Center

Date: March 24, 1978

"Price Allocation Guidelines"

Author: R.W. Aster

Report No.: 5101-68, JPL/LSA Data Center

Date: May 12, 1978

"Effect of Grain Boundary in Si Sheet on Minority Carrier Diffusion Length and Solar Cell Efficiency"

Authors: Sand/Koliwad

Report No.: 5101-69, JPL/LSA Data Center

Date: June 15, 1978

"SAMIS III Design Document (Solar Array Manufacturing Industry Simulation) Release 1"

Authors: Chamberlain/Firnett

Report No.: 5101-70, JPL/LSA Data Center

Date: March 24, 1978

"SAMIS III Computer Program Source Code"

Author: R.G. Chamberlain

Report No.: 5101-71

Date: March 24, 1978

"Encapsulant Candidate Materials for 1982 Cost Goals"

Author: Hugh Maxwell

Report No.: 5101-72

Date: June 1975

"Determination of Bulk Diffusion Lengths for Angle-Lapped Semi-Conductor Material via the Scanning Electron Microscope - A Theoretical Analysis"

Author: O. Von Roos

Report No.: 5101-73

Date: May 31, 1978

"The Penetration of the International Market by Domestically Produced Photovoltaic Power Systems/A Survey of Recent Estimates"

Authors: G.M. Ziman and J.L. Smith

Report No.: 5101-75

Date: May 30, 1978

"Thermal and Other Tests of Photovoltaic Modules Performed in Natural Sunlight"

Author: J.W. Stultz

Report No.: 5101-76

Date: July 31, 1978

"Effect of Photodegradation on Chemical Structure and Surface Characteristics of Silicone Pottants Used in Solar Cell Modules"

Author: A. Gupta

Report No.: 5101-79

Date: August 18, 1978

"Block IV Solar Cell Module Design and Test Specification for Residential Applications"

Author: LSA Engineering Department

Report No.: 5101-83

Date: November 1, 1978

"Bias-Humidity Testing of Solar Cell Modules"

Author: A. Hoffman and E. Miller

Report No.: 511-79

Date: August 18, 1978

"Block IV Solar Cell Module Design and Test Specification for Residential Applications"

Author: LSA Engineering Department

Report No.: 5101-83

Date: November 1, 1978

"Bias-Humidity Testing of Solar Cell Modules"

Author: A. Hoffman and E. Miller

Report No.: 5101-84

Date: October 15, 1978

C. 1978 Contractor Quarterly Reports

Silicon Material Task

"Development of a Model and Computer Code to Describe Solar Grade Silicon Production Processes"

Author: Aerochem Research Laboratories, Inc.

Report Nos.: 954862-78/2 (January-March 1978), 954862-78/3 (April-June 1978)

"Evaluation of Selected Chemical Processes for Production of Low-Cost Silicon"

Author: Battelle

Report No.: 954339-78/10 (January-March 1978)

"Develop Silicone Encapsulation Systems for Terrestrial Silicon Solar Arrays"

Author: Dow Corning Corporation

Report Nos.: 954995-78/1 (February-June 1978), 954995-78/2 (July-September 1978)

"Process Feasibility Study in Support of Silicon Material Task I"

Author: Lamar University

Report Nos.: 954343-78/10 (December 1977-February 1978), 954343-78/11 (March-May 1978), 954343-78/12 (June-August 1978)

"Semiconductor Grade, Solar Silicon Purification Project"

Author: Motorola, Inc. Semiconductor Group

Report Nos.: 954442-78/9 (January-March 1978), 954442-78/10 (April-June 1978)

"Study of the Effects of Impurities on the Properties of Silicon Materials and Performance of Silicon Solar Cell"

Author: SAH Associates

Report No.: 954685-78/1 (January-March 1978)

"LSA Silicon Material Task Closed-Cycle Process Development"

Author: Texas Instruments Incorporated

Report No.: 955006-78/1 (August-September 1978)

"Feasibility of Low-Cost, High Volume Production of Silane and Pyrolysis of Silane to Semiconductor-Grade Silicon"

Author: Union Carbide Corporation

Report Nos.: 954334-78/6 (January-March 1978), 954334 78/7 (April-June 1978)

"Development of a Process for High Capacity Arc Heater Production of Silicon for Solar Arrays"

Author: Westinghouse Electric Corporation

Report Nos.: 954589-78/5 (January-March 1978), 954589-78/6 (April-June 1978)

"Effect of Impurities and Processing on Silicon Solar Cells"

Author: Westinghouse R&D Center

Report Nos.: 954331-78/2 (January-March 1978), 954331-78/3 (April-June 1978)

Large Area Silicon Sheet Task

"Silicon-on-Ceramic Solar Cell Development"

Author: Honeywell Corporate Material Sciences Center

Report Nos.: 954356-78/5 (December 1977-March 1978), 954356-78/6 (March-June 1978)

"Continuous Czochralski Growth"

Author: Kayex Corporation

Report Nos.: 954888-78/2 (January-March 1978), 954888-78/3 (April-June 1978)

"Large Area Silicon Sheet by EFG"

Author: Mobil Tyco Solar Energy Corporation

Report Nos.: 954355-78/5 (January-March 1978), 954355-78/6 (April-June 1978)

"Laser-Zone Growth in a Ribbon-to-Ribbon (RTR) Process Silicon Sheet Growth Development for the Large-Area Silicon Sheet Task of the Low Cost Silicon Solar Array Project"

Author: Motorola, Inc. Semiconductor Group

Report Nos.: 954376-78/5 (January-March 1978), 954376-78/6 (April-June 1978)

"Epitaxial Silicon Growth for Solar Cells"

Author: RCA Laboratories

Report Nos.: 954817-78/2 (January-March 1978), 954817-78/3 (April-June 1978)

"LSA Large-Area Silicon Sheet Task Continuous Liquid Feed Czochralski Growth"

Author: Siltec

Report Nos.: 954886-78/2 (January-March 1978), 954886-78/3 (April-June 1978), 954886-78/4 (July-September 1978)

"LSSA Large Area Silicon Sheet Task Continuous Czochralski Process Development"

Author: Texas Instruments Incorporated

Report Nos.: 954887-78/2 (January-March 1978), 954887-78/3 (April-June 1978)

"Slicing of Silicon into Sheet Material"

Author: Varian Associates

Report Nos.: 954374-78/5 (December 1977-March 1978), 954374-78/6 (March-June 1978)

"Development of Advanced Methods for Continuous Czochralski Growth"

Author: Varian Associates

Report Nos.: 954884-78/2 (January-March 1978), 954884-78/3 (March-July 1978)

"Silicon Web Process Development"

Author: Westinghouse R&D Center

Report No.: 954654-78/4 (April-June 1978)

Encapsulation Task

"Integral Glass Encapsulation for Solar Arrays"

Author: Spire Corporation

Report Nos.: 954521-78/5 (November 1977-February 1978), 954521-78/6 (February-May 1978), 954521-78/7 (May-August 1978)

"Investigation of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants"

Author: Springborn Laboratories, Inc.

Report No.: 954527-78/5 (November 1977-February 1978)

Automated Array Assembly Task

"Process Development for Automated Solar Cell and Module Production"

Author: MB Associates

Report Nos.: 954882-78/5 (November 1977-March 1978), 954882-78/10 (April-June 1978)

"Phase 2 of the Automated Array Assembly Task of the Low Cost Silicon Solar Array Project"

Author: Motorola, Inc. Semiconductor Group

Report Nos.: 954847-78/2 (January-March 1978), 954847-78/3 (April-June 1978)

"Automated Array Assembly Phase II"

Author: RCA Laboratories

Report Nos.: 954868-78/2 (January-March 1978), 954868-78/3 (April-June 1978)

"Phase 2 Array Automated Assembly Task Low Cost Silicon Solar Array Project"

Author: Sensor Technology, Incorporated

Report Nos.: 954865-78/2 (January-March 1978), 954865-78/3 (April-June 1978)

"Phase 2 of the Array Automated Assembly Task for the Low Cost Silicon Solar Array Project"

Author: Solarex Corporation

Report Nos.: 954854-78/2 (January-March 1978), 954854-78/3 (April-June 1978)

"Array Automated Assembly Phase 2"

Author: Spectrolab, Inc.

Report Nos.: 954853-78/2 (January-March 1978), 954853-78/3 (April-June 1978)

"Development of Pulsed Processes for the Manufacture of Solar Cells"

Author: Spire Corporation

Report Nos.: 954786-78/04 (January-March 1978), 954786-78/05 (April-June 1978)

"Automated Array Assembly Phase 2"

Author: Texas Instruments Incorporated

Report Nos.: 954881-78/2 (January-March 1978), 954881-78/3 (April-June 1978)

"Phase 2 of the Array Automated Assembly Task for the Low Cost Silicon Solar Array Project"

Author: Westinghouse R&D Center

Report Nos.: 954873-78/02 (January-March 1978), 954873-78/03 (April-June 1978)

4. The following publications and technical reports are related to the Concentration Systems projects described on pages 245-27

"Performance of a One Kilowatt Concentrator Photovoltaic Array Utilizing Active Cooling"

Publication: Proceedings of the IEEE Photovoltaic Specialist Conference

Date: July 1978

"Reliability Concerns and Life-Test Procedures for Concentrator Solar Cells"

Author: W.V. McLevige

Report No.: SAND 78-0875, Sandia Laboratories

Date: July 1978

"Development of High-Efficiency p^+-n-n^+ Back Surface Field Silicon Solar Cells"

Author: J.G. Fossum, et al.

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference

Date: June 1978

"Combined Photovoltaic Thermal System Studies"

Author: D.L. Evans, et al.

Report No.: SAND 78-7031, Arizona State University

Date: August 1978

"Photovoltaic Concentrator Test and Evaluation Plan"

Author: G.J. Jones

Report No.: SAND 78-0945

Date: June 1978

"Design and Construction of a 50 kVA Power Conditioning Unit for Photovoltaic Power Systems - Conceptual Design"

Author: F.C. Stump, et al.

Report No.: SAND 78-97020, Sandia Laboratories

Date: April 1978

"Palladium Passivated Titanium-Silver Conductor Patterns for High-Illumination-Intensity Silicon Solar Cells"

Author: D.J. Sharp

Report No.: SAND 78-0685, Sandia Laboratories

Date: September 1978

"Real-Time Environmental and Performance Testing of Concentrating Photovoltaic Arrays"

Authors: J.L. Watkins and D.A. Pritchard

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference

Date: June 1978

"Status of the DOE Photovoltaic Concentrator Technology Development Project"

Author: M.W. Edenburn, et al.

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference

Date: June 1978

"System Design Report for a 10 Kilowatt Photovoltaic Concentrator System"

Author: J.A. Castle

Report No.: SAND 78-70

Date: May 1978

"10-Kilowatt Photovoltaic Concentrator Array"

Author: R.L. Donovan and S. Broadbent

Report No.: sand 78-7024, Sandia Laboratories

Date: May 1978

"Terrestrial Photovoltaic Power Systems with Sunlight Concentration-Annual Progress Report 1977"

Author: C.E. Backus, et al.

Report No.: SAND 78-7026, Sandia Laboratories

Date: May 1978

"Physical Operation of Back-Surface-Field Silicon Solar Cells"

Author: J.G. Fossum

Publication: IEE Trans. Electron Devices, Vol. ED-24, pp. 322-325

Date: April 1977

"Performance of n-p Silicon Solar Cells in Concentrated Sunlight"

Authors: E.L. Burgess and J.G. Fossum

Publication: IEEE Trans. Electron Devices, Vol ED-24, pp. 433-438

Date: April 1977

"Application of the Superposition Principle to Solar Cell Analyses"

Authors: F.A. Lindholm and E.L. Burgess

Publication: IEEE Trans. Electron Devices

"Computer Analysis of Resistance and Nonuniform Illumination Effects on Concentrator Solar Cells"

Author: K. Mitchell

Publication: Proceedings IEDM, Washington D.C.

Date: December 5-7, 1977

"The Dependence of Open-Circuit Voltage on Illumination Level in p-n Junction Solar Cells"

Authors: J.G. Fossum and F.A. Lindholm

Publication: IEEE Trans. Electron Devices, Vol. ED-24, pp. 325-329

Date: April 1977

"Proceedings, DOE Photovoltaic Concentrator Systems Workshop, May 24-26, 1977"

Sponsored by: Department of Energy and Sandia Laboratories

Published by: College of Engineering and Applied Sciences, Arizona State University

"Application of Compound Parabolic Concentrators to Solar Photovoltaic Conversion," Argonne National Laboratories

Author: R.L. Cole, et al.

Report No.: ANL-77-42

Date: February 1977

"Concentrating Photovoltaic Solar Array (CPSA) Conceptual Design Party"

Author: C.J. Bishop

Report No.: SAND 77-7019, Sandia Laboratories and Boeing Engineering Report No. 0277-10045-1

Date: May 1977

"Photovoltaic Energy Conversion Using Concentrated Sunlight"

Author: E.L. Burgess

Publication: Optical Engineering, Vol. 16, No. 3

Date: May-June 1977

5. The following publications and technical reports are related to the Systems and Definition Development Systems projects described on pages 255-275.

"PVSS-A Photovoltaic System Simulation Program"

Authors: L.H. Goldstein and G.R. Case

Publication: Solar Energy, Vol. 21, No. 1, pp. 37-43

Date: 1978

"Optimization of Terrestrial Photovoltaic Systems"

Author: J.K. Linn

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference

Date: June 1978

"Status of the DOE Photovoltaic Systems Engineering and Analysis Project"

Authors: D.G. Schueler and G.J. Jones

Publication: Proceedings of the 13th IEEE Photovoltaic Specialist Conference

Date: June 1978

"Hourly Insolation and Meteorological Data Bases Including Improved Direct Insolation Estimates"

Authors: C.M. Randall and M.E. Whitson Jr.

Report No.: SAND 78-7047, The Aerospace Corporation

Date: December 1977

"Photovoltaic Applications Definition and Photovoltaic Systems Definition Study in the Agricultural Sector," Task 1 Report

Author: R.W. Mengel, et al.

Report No.: SAND 78-7030, The BDM Corporation

Date: July 1978

"Application Analysis and Photovoltaic System Conceptual Designs for Service/Commercial/Institutional and Industrial Sectors," Task 1 Report

Author: R.A. Whisnant, et al.

Report No.: SAND 78-7032, Research Triangle Institute

Date: July 1978

"Energy Storage Consideration in Photovoltaic Central Station Utility Applications"

Authors: D.G. Schueler and G.J. Jones

Publication: Proceedings of the 1978 Meeting of the American Section of the International Solar Energy Society, Vol. 2.2, pp. 332

Date: August 1978

"Generation of Typical Meteorological Years for 26 SOLMET Stations"

Author: I. Hall, et al.

Report No.: SAND 78-1601, Sandia Laboratories

Date: August 1978

"Photovoltaic Systems Definition Project FY77 Annual Report"

Author: E.C. Boes

Report No.: SAND 78-0942, Sandia Laboratories

Date: October 1978

"Design of Low-Cost Structures for Photovoltaic Arrays-Task 2 Technical Report-Study of Structural Designs"

Author: H.A. Franklin, et al.

Report No.: SAND 78-7033, Sandia Laboratories

Date: July 1978

"Low-Cost Structures for Photovoltaic Arrays-Task 1 Report"

Authors: M.C. Keeling and P. Masser

Report No.: SAND 78-7029, Sandia Laboratories

Date: July 1978

"Photovoltaic System Performance, Applications, and Prospects for Economic Viability in Central Utility Networks and Distributed Energy Supply"

Publication: Transactions of the American Nuclear Society 23rd Annual Meeting, New York, N.Y., Vol. 26

Date: June 1977

"Solar Photovoltaic Power Systems"

Authors: L.M. Magid, B.W. Marshall, and D.G. Schueler

Publication: IEEE Power Engineering Society 1977 Summer Meeting July 17-22, 1977, Mexico City, Mexico, IEEE Catalog No. 77 CH1193-2 PWR

"Photovoltaic System Analysis Program-SOLCEL"

Author: J.K. Linn

Report No.: SAND 77-1268, Sandia Laboratories

Date: August 1977

"Conceptual Design and Systems Analysis of Photovoltaic Systems," Final Report

Author: General Electric Company, Space Division

Report No. ALO-3686-14, 3 Vol.

"Photovoltaic Systems Concept Study," Final Report Spectrolab, Inc.

Report No.: ALO-2748-12, 5 vol.

"Photovoltaic System Analysis Program"-SOLCEL

Author: J.K. Linn

Report No.: SAND 77-1268, Sandia Laboratories

Date: August 1977

"Availability of Direct, Total, and Diffuse Solar Radiation for Fixed and Tracking Collectors in the USA"

Author: E. Boes, et al.

Report No.: SAND 77-0885, Sandia Laboratories

Date: August 1977

"Estimating Monthly Means of Daily Totals of Direct Normal Solar Radiation"

Authors: E. Boes, and I. Hall

Report No.: SAND 77-0874, Sandia Laboratories

Date: July 1977

"Record of the Photovoltaic Power Conditioning Workshop," October 13-14, 1976

Report No.: SAND 77-0393, Sandia Laboratories

Date: March 1977

6. The following publications and technical reports are related to the System Application Experiments projects described on pages 293-326.

A. Published Documents Prepared by the Massachusetts Institute of Technology

"The Mead 25 kW Photovoltaic System"

Author: L.L. Bucciarelli, et al.

Publication: 1978 IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

"Design, Development and Implementation of Data Acquisition Systems for PV Tests and Applications Project"

Author: J.D. Cremin

Report No.: C00-4094-24

Date: October 31, 1978

"Summary of Field Experience of PV Modules at Various MIT/LL Test Sites:

Author: S.E. Forman

Report No.: C00-4094-8

Date: March 22, 1978

"Visual Defects in Terrestrial Photovoltaic Modules"

Author: S.E. Forman

Report No.: C00-4094-6

Date: March 21, 1978

"Safety Procedures for the 25 kW Solar Photovoltaic Array at Mead, Nebraska"

Authors: S.E. Forman and E.E. Landsman

Report No.: C00-4094-7

Date: April 7, 1978

"Field Testing and Evaluation of PV Module Performance"

Author: S.E. Forman

Publication: 1978 IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

"Endurance and Soil Accumulation Testing of PV Modules at Various MIT/LL Test Sites"

Author: S.E. Forman

Report No.: C00-4094-23

"Photovoltaic Applications for the National Park Service"

Authors: P.O. Jarvinen and P.C. Ross

Publication: 12th Intersociety Energy Conversion and Engineering Conference, Washington, D.C.

Date: August 28-September 2, 1977

"Natural Bridges National Monument, Utah - Solar Photovoltaic Power System Design"

Author: P.O. Jarvinen

Publication: 2nd National Conference on Technology for Energy Conservation, Albuquerque, NM

Date: January 24-27, 1978

"Solar Energy Alternatives for the United States Embassy and for Rural Development Projects within the Republic of Upper Volta"

Author: E.C. Kern

Report No.: C00-4094-5

Date: March 7, 1978

"Motor Starting with PV Systems"

Author: E.E. Landsman

Publication: 1978 IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

"Maximum Power Trackers for Photovoltaic Arrays"

Author: E.E. Landsman

Publication: 1978 IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

"Design of the Natural Bridges National Monument 100 kW PV Power System"

Author: E.F. Lyon, et al.

Publication: 1978 IEEE Photovoltaic Specialist Conference, Washington, D.C.

Date: June 5-8, 1978

"25 kW PV Powered Irrigation and Grain Drying Experiment"

Author: R.W. Matlin

Publication: International Solar Energy Congress, New Delhi, India

Date: 1978

"PV Powered Irrigation Experiments in the U.S."

Author: R.W. Matlin

Publication: Atelier Pompage Solaire, Perpignan, France

Date: July 3-8, 1978

"The Economics of Adopting Solar Photovoltaic Energy Systems in Irrigation"

Authors: R.W. Matlin and M.T. Katzman

Report No.: C00-4094-2

Date: July 11, 1977

"The 25 Kilowatt Photovoltaic Powered, Agricultural Experiment in Mead, Nebraska"

Author: R.W. Matlin, et al.

Report No.: C00-4094-4

Date: April 21, 1978

"A Subscale (25 kW) PV Powered Irrigation Experiment"

Authors: R.W. Matlin, et al.

Publication: New Options in Energy Technology Conference, San Francisco, CA

Date: August 2-4, 1977

"The Economics of Solar Photovoltaic Energy Systems for Crop Irrigation in the U.S."

Authors: R.W. Matlin and M.T. Katzman

Publication: American Journal of Agriculture Economics, Vol. 60

Date: November 1978

"A Flywheel Energy Storage and Conversion System"

Author: A.R. Millner

Report No.: C00-4094-25

"Mead PV System Controller"

Author: A.R. Millner

Report No.: C00-4094-27

"A Low-Drag, Low-Power Magnetic Bearing"

Author: A.R. Millner

Publication: 3rd International Workshop on Rare Earth-Cobalt Magnets and their Applications, University of California, San Diego, CA

Date: June 27-30, 1978

"A High-Speed, High-Efficiency Permanent Magnetic Motor Generator"

Author: A.R. Millner

Publication: 3rd International Workshop on Rare Earth-Cobalt Magnets and Their Applications, University of California, San Diego, CA

Date: June 27-30, 1978

"Sun Following Pyrheliometer Mounts for Insolation Data Collection"

Authors: C. Much and D. Stuart

Report No.: C00-4094-9

Date: August 2, 1978

"Photovoltaic Applications in the Southwest for the National Park Service"

Authors: C.R. Peatfield and P.O. Jarvinen

Report No.: C00-4094-3

Date: April 28, 1977

"Photovoltaic Power System Field Tests"

Authors: M.D. Pope and R.W. Matlin

Publication: 1977 Photovoltaic Solar Energy Conference, Luxembourg

Date: September 27-30, 1977

"Description of the Mead PV Power System"

Author: W. Romaine

Report No.: C00-4094-10

"Test Plan for Residential Testing at MIT/LL PV System Test Facility"

Author: S.B. Sacco

Report No.: C00-4094-22

"Photovoltaic Power in Less Developed Countries"

Author: D.V. Smith

Report No.: C00-4094-1

Date: March 27, 1977

"Consideration of Different Systems to the Solar PV Energy Program"

Authors: M. Twersky and P.E. Fischbach

Report No.: C00-4094-21

B. Reports Prepared by the National Aeronautics and Space Administration in Conjunction with the Department of Energy

"Test Facility for Solar-Cell Reference Conditions"

Author: ERDA/NASA

Report No.: 1022/76/1 (NASA CP-2010)

Date: November 10-12, 1976

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