OFFICE OF SOLAR HEAT TECHNOLOGIES
FISCAL YEAR 1988
ANNUAL OPERATING PLAN

1399

JULY 1988

U.S. DEPARTMENT OF ENERGY
OFFICE OF SOLAR HEAT TECHNOLOGIES
WASHINGTON, D.C. 20585

OFFICE OF SOLAR HEAT TECHNOLOGIES FISCAL YEAR 1988 ANNUAL OPERATING PLAN

JULY 1988

U.S. DEPARTMENT OF ENERGY
OFFICE OF SOLAR HEAT TECHNOLOGIES
WASHINGTON, D.C. 20585

TABLE OF CONTENTS

OFFICE OF SOLAR HEAT TECHNOLOGIES
FISCAL YEAR 1988
ANNUAL OPERATING PLAN

I. INTRODUCTION

The Fiscal Year 1988 Annual Operating Plan (AOP) for the Office of Solar Heat Technologies is the primary management tool used by the Office to implement and track its FY 1988 programs. The AOP provides a description of program objectives and structure, planned activities, and funding plans.

Incorporated within this Office AOP as appendices are the AOPs for the two Solar Heat programs: the Solar Buildings Technology program and the Solar Thermal Technology program. These appendices provide the same technical and programmatic information summary as the Office AOP, but in more detail.

II. BACKGROUND

A. Legislation

The Active, Passive, and Solar Thermal programs that were brought together in the Office of Solar Heat Technologies during the summer of 1981 had their principal origins in legislation passed by the 93rd Congress in 1974. These Acts, along with a reorganization act passed in 1977, are:

- The Solar Heating and Cooling Demonstration Act of 1974 (P.L. 93-409) established a demonstration program to be implemented by the National Aeronautics and Space Administration (NASA), the Department of Housing and Urban Development (HUD), and the National Science Foundation (NSF). The program was intended to demonstrate the use of solar heating and cooling technologies for residential and commercial building applications.

- The Energy Reorganization Act of 1974 (P.L. 93-438) consolidated solar research related functions into the Energy Research and Development Administration (ERDA).

- The Solar Energy Research, Development, and Demonstration Act of 1974 (P.L. 93-473) established a solar energy coordination and management project within ERDA.

- The Federal Non-Nuclear Energy Research and Development Act of 1974 (P.L. 93-577) established a national program of basic and applied research and development, and mandated commercial demonstrations of advanced solar technologies.

- The Department of Energy Reorganization Act of 1977 (P.L. 95-91) established the Department of Energy (DOE) and transferred to DOE most of the solar energy related activities from the Federal Energy Administration (FEA), ERDA, and other agencies and departments.

The thrust of the early legislation was to advance the rate of commercialization of solar heat energy technologies across a broad front. Concurrent programs were initiated to support research and development, to demonstrate the viability of current technology, to provide financial incentives for installing solar systems, and to increase solar awareness by industry and the general public. R&D functions were performed by ERDA, the Atomic Energy Commission (AEC) and NASA; market development and consumer-oriented activities by FEA; and demonstration projects by these agencies as well as other Federal organizations.

In October 1977, all Federal solar energy R&D activities were consolidated in the newly established Department of Energy. The near-term technologies and market/consumer-oriented activities were organized under an Assistant Secretary for Conservation and Solar Applications (CS) while technologies requiring more R&D effort were assigned to an Assistant Secretary for Energy Technology (ET).

In late 1979, DOE was reorganized. All solar programs were brought together under an Assistant Secretary for Conservation and Solar Energy, but the present solar heat technology programs were located in two offices: Active and Passive (along with the Photovoltaics program) in the Office of Solar Applications for Buildings; while the Solar Thermal Technologies were placed in the Office of Solar Applications for Industry.

B. Transition of Programs to R&D

DOE was restructured in the Spring of 1981 and the programs were redirected to emphasize long-term, high risk, potentially high pay-off R&D through the proof-of-concept phase. Market-related activities were eliminated based on the premise that industry would conduct those necessary activities related to near-term commercialization. The solar energy organization was realigned by technology instead of end-use applications, and the three solar heat technology programs (Active, Passive, and Solar Thermal) were brought together in the Office of Solar Heat Technologies.

In the Fall of 1985 the Office of Solar Heat Technologies was restructured to combine the active and passive solar technologies into the Solar Buildings Technology program. Currently, the Office of Solar Heat Technologies includes the Solar Buildings and Solar Thermal Technology programs. Figures 1 and 2 depict the current organizational structure of the Office of Solar Heat Technologies. (Figures are presented following page 25.)

III. TECHNOLOGY OVERVIEW AND PROGRAM STRUCTURE

In this section, a description of the program structure and current status is provided to serve as a baseline for the FY 1988 goals, objectives, and strategies presented in Section IV. The program description includes summaries of the status of the technologies under development, the work breakdown structure of programs, and the key accomplishments to date.

A. Technologies

There are many ways in which solar radiation can be converted into useful thermal energy. All involve collection, conversion, and distribution components which differ primarily as a function of the temperature at which the energy is used. The Office of Solar Heat Technologies deals with delivery temperatures which range from approximately 27°C (80°F) to over 1370°C (2500°F). Active solar buildings technologies (using flat plate collectors) generally operate at delivery temperatures below 90°C (195°F), although some compound parabolic concentrator collectors operate at delivery temperatures between 120°C and 150°C (250°F and 300°F). Most passive solar systems deliver hot air or water below 65°C (150°F). Solar thermal parabolic troughs operate at temperatures of 100°C to 315°C (212°F to 600°F) and are usually considered to be most suitable for industrial process heat applications. On the other hand, both parabolic dishes and central receiver systems can produce temperatures up to 1370°C (2500°F) or more. Currently, most of the solar thermal research and development is focused on electricity generation and process heat applications requiring temperatures up to 600°C (1100°F).

1. Solar Buildings

a. Solar Heating

Solar heating technology encompasses passive and active space and water heating. Applications for solar heating are found in both residential and nonresidential buildings. The major research opportunities for solar heating technology exist in the areas of efficiency enhancement for high solar contribution passive heating systems, and active solar space and water heating systems. Solar heating research activities in FY 1988 will focus on generic active heating systems and supporting systems effectiveness research. Generic solar heating systems employ basic configurations which have been synthesized from current industry practice and state-of-the-art research results. The development of test procedures will continue during the coming year as will study of the central solar heating system with seasonal storage concept. Research on advanced systems will also continue.

b. Solar Cooling

The objective of solar cooling research is to provide a variety of cost-competitive options that can supply a significant portion of building cooling requirements in the broadest range of building types and geographic locations. Desiccant and absorption cooling, and cooling based on natural ventilation, radiation, and dehumidification have emerged as the options offering the greatest opportunity for meeting this objective. Research will continue in several areas including: solid desiccant materials and improved heat and mass transfer designs, building dehumidification using passive strategies, and open cycle absorption cooling.

c. Daylighting

Daylighting technologies, or technologies which displace fluorescent and incandescent lighting with sunlight, are widely available yet generally underused. Daylighting strategies have been identified which can reduce building energy lighting requirements by more than 50%. Additionally, although daylighting generally requires more glazing area than would be used in conventional construction, studies have shown that use of daylighting technologies can be used without increasing building cooling loads. Research is aimed at providing even greater percentages of perimeter lighting with improved comfort and reduced cooling energy loads. In addition, advanced daylighting materials and strategies that can deliver core lighting in large buildings are under development. The major research opportunities for improving daylighting technologies are in the areas of optical switching films for apertures, core daylighting materials and techniques, and atria.

d. Solar Systems Integration

Systems integration is the activity which investigates the impact of the various solar heating, cooling, and daylighting technologies on overall building performance and on means to optimize their combined performance. This research area is aimed at the development of technical and cost data as well as design tools to facilitate the widespread use of solar buildings technology. The principal focus of this area will be on the preparation of design guidelines for use by the building industry, development of a solar building energy analysis procedure, and development of short-term test procedures to evaluate long-term performance of solar systems.

2. Solar Thermal

a. Central Receiver

In a central receiver system, a field of mirrors (heliostats) is used to focus the sun onto a fixed, tower-mounted receiver. Each heliostat tracks the sun along two axes. Usually the energy is transferred from the receiver, using transport and storage media, to operate a large Rankine cycle steam turbine generator. Present heliostats, at 150-200m^2 in area, are four times as large as the original Solar One heliostats (40m^2) and have reflector surfaces capable of achieving greater than 90% reflectance with long-life. Advanced heliostats using the "stressed membrane" concept have the potential of reducing the heliostat cost from the current \$150/m^2 to \$40/m^2. Receivers operating with molten salt working fluids are being investigated because they have higher solar flux and temperature limits than earlier steam systems. The central receiver Molten Salt Electric Experiment completed in July 1985 has provided operational experience with molten salt concepts to several industry/utility teams. Currently, molten salt receiver, pump, and valve subsystems/components experiments are underway at the Central Receiver Test Facility, Albuquerque, New Mexico. Advanced receiver research is also being conducted on direct absorption receivers (DARs) which are capable of achieving higher solar radiant flux and temperature performance. Solar One, a cost-shared 10 MWe pilot plant (operational since 1982) successfully completed its three-year power production phase in August 1987, and will continue to operate in a semi-commercial phase (5 days a week) through July 1988 under funding by DOE and EPRI. In addition, a group of western utilities are studying appropriate paths to the next generation of central receiver technologies in utility applications. Phase I of the utilities study has been completed with the conceptual design of the preferred configuration for the solar power tower. The results verify the ability to attain DOE mid-term cost goals for molten salt central receiver plants.

b. Parabolic Dish

Parabolic dishes use a two-axis tracking concept and focus the sunlight onto receivers located at the focal point of each dish. Dishes can be used in stand-alone or large multi-module systems. These systems may have one large centrally-located engine, or many smaller engines located at the focal point of each dish. In addition to electricity generation, dishes can also supply energy for IPH applications. Similar to central receiver technology, dish systems will also benefit from recent developments in lightweight, low-cost stretched membrane and other concentrator technologies. In the area of receivers, the reflux receiver has been identified as a potential receiver option for Stirling engines and thermochemical transport. The reflux receiver concept promises simple, low-cost, reliable, and efficient receivers and readily permits fossil fuel hybridization. Several dish-mounted engines (that convert each individual concentrator's thermal energy into electricity) have undergone substantial testing and evaluation, including Rankine, Brayton, and Stirling cycle engines. However, engine reliability is a critical area that still needs improvement. Work continues on improving the kinematic Stirling engine, and thermochemical conversion R&D, as well as on developing a free-piston Stirling engine. The latter engine concept, being developed in cooperation with NASA space program, has the potential of achieving the long-term goals of high reliability and performance at competitive cost. In addition, research is underway on a thermochemical cell in which spent chemicals are regenerated by solar energy to produce electricity. The DOE-sponsored 3 MWt system at Shenandoah, Georgia has been operational since 1982, and uses parabolic dish modules to heat a silicone-based fluid to provide process heat, air conditioning, and electric power. Title for the system has passed to the Georgia Power Company, who continues to operate the plant. A privately funded 4.9 MWe parabolic dish project at Warner Springs, California has been constructed by LaJet Energy Company using 700 of its 7.4m diameter dish concentrators, and is supplying electricity to the San Diego Gas & Electric Utility grid.

c. Parabolic Trough

The parabolic trough collector is the most nearly commercial of the current solar thermal technologies. Systems are commercially available with thermal efficiencies greater than 60 percent at installed capacity costs of approximately $400/m^2$ of collector area. Over 35 industrial process heat (IPH) parabolic trough systems, some as large as 2300m^2, have been successfully constructed and operated. In addition, five parabolic trough electric generating projects, SEGS I-V, are currently operational. These five privately funded (non-DOE funded) projects constructed by Luz Engineering are capable of generating approximately 135 MWe and supplying it to the Southern California Edison grid. The IPH and electricity-generating trough projects provide needed confidence among the user community by demonstrating quality system performance and durability.

B. **Program Structure**

The Office of Solar Heat Technologies' program structure reflects the relationship of management organization to key elements of the technology development process, as shown in Figure 2.

- Solar Buildings Technology Program - encompasses heating (both passive and active), cooling (desiccant, absorption and passive), daylighting, and systems integration.

- Solar Thermal Technology Program - includes both central receiver and distributed receiver technologies for use in medium and high temperature applications, including electric power generation, industrial process heat, and photo/thermochemical applications.

Activities within the programs include materials and components research, systems research, collection technology, energy conversion technology, and systems and applications technology.

C. **FY 1987 Major Accomplishments**

1. Solar Buildings Technology Program -- FY 1987 Accomplishments

The program took significant strides in FY 1987. Major progress was achieved in all aspects of solar buildings research. These accomplishments are described below.

a. Heating Technology Accomplishments

- Completed design manual for commercial size active solar water heating systems. This manual, which provides complete details on all aspects of solar design, incorporated more than ten years of Federal and private sector experience.

- Developed several new compound parabolic collector designs that show promise of improved performance without increasing cost.

- Drafted a series of design information booklets on passive solar design and construction for residences.

- Devised method for improving the fire resistance of alkyl-hydrocarbon phase change material impregnated in gypsum wallboard.

b. Cooling Technology Accomplishments

- Performed analysis of solar-regenerated desiccant dehumidifiers which revealed that a Coefficient of Performance (COP) of 1.7 is achievable.
- Tested 22 polymer materials for use as desiccants in high-COP desiccant dehumidifiers. Several polymers with the necessary characteristics were found.
- Conducted analysis of open cycle absorption system which indicated that this type of system could provide up to 70% of the cooling requirements of residential buildings in many regions of the U.S.
- Continued development of models for passive cooling in hot humid climates.

c. Daylighting Technology Accomplishments

- Demonstrated plasma enhanced chemical vapor deposition (PECVD) process for fabricating multilayer electrochromic devices.
- Fabricated small-scale five layer electrochromic device and established stable cyclic reversibility.
- Fabricated and demonstrated experimental holographic diffractive structure.
- Developed analytical model characterizing the performance of light guides.
- Established capability of producing larger (10"x10") samples of silica aerogel glazing and reduced coloration problems with the glazing.
- Developed and tested short-term test method for predicting long-term performance of daylighting systems.

d. Solar Systems Integration Accomplishments

- Introduced prototype passive solar design guidelines for homebuilders.
- Developed protocol for determining the long-term thermal performance of a building from short-term test data. This activity was a cooperative effort with industry.
- Analyzed performance of heat absorbing windows with thermally coupled storage. This passive strategy could improve performance of passive buildings by 30%-50%.

2. Solar Thermal Technology Program -- FY 1987 Accomplishments

Significant progress was made within the Solar Thermal Technology program during Fiscal Year 1987. A summary of the Fiscal Year 1987 major accomplishments of the Solar Thermal Technology Program is given below for the areas of Collection Technology, Conversion Technology, Systems and Applications Technology, and Planning and Assessment.

a. Collection Technology Accomplishments

- Continued outdoor weathering tests at several sites demonstrating that silvered polymers can have excellent initial optical properties when used with mirrors in a stretched membrane configuration or mounted on stiff substrates. ECP 300 or glass substrate maintained performance levels of reflectance of greater than 90% at 4 mrad after 89 weeks at Golden, Colorado and greater than 90% at 8.4 mrad after 15 months at Arizona and Florida. ECP 300X shows no silver corrosion after 3.4 years outdoors in Golden. These results are approaching the long-term program goal to obtain a mirror having a reflectance of at least 90% at 2 mrad with a 5 year lifetime.

- Benzotriazole-type UV absorbers were selected as the primary stabilizer system for protection of mirror surfaces and backings. The system will undergo further research and evaluation at SERI.

- Small scale experiments using the DAR Inconel test loops were conducted at SERI to understand the nitrate salt film behavior with and without a dopant using simulated solar flux.

- Both Innovative Parabolic Dish Concentrator prototypes have been completed and installed at the DRTF for testing.

- Detailed designs of two 150m^2 stressed membrane heliostats were completed during FY1986. Both 50m^2 prototypes have been installed and tested at the CRTF. Contracts are in place for further development and include the fabrication of two improved prototypes.

- Experiments were conducted to assess the behavior of nitrate salt films for use with DAR systems.

- A 20kW thermochemical receiver/reformer built by Sandia began testing at the Weizmann Institute of Science in Israel as part of a United States-Israel bilateral agreement.

- Installation of a 5 MWt subscale molten salt cavity receiver (configured like manufactured article) for testing at the CRTF has been completed, and operation initiated.

- Installation of a large area (200m^2) glass metal heliostat at the CRTF has been completed and testing initiated. Both the 150m^2 and 200m^2 units will continue testing during FY1988.

- Contracts have been awarded to Solar Kinetics, Inc. and LaJet Energy Company to develop stretched membrane dishes. Phase I design reviews were conducted during FY1987.

b. Conversion Technology Accomplishments

- Research continued on free-piston Stirling engines under cooperative agreement with NASA/Lewis Research Center. Preliminary and final concept designs were reviewed.

- SERI completed a two-year research plan for the Regenerative Thermoelectrochemical Converter (RTEC). Work will be performed under a cost-shared agreement with Hughes Aircraft. In addition, SERI initiated development of a computer model to characterize a dish-RTEC system.

- A cost-to-manufacture study of the MTI and STC free-piston Stirling engine designs has been conducted by Pioneer Engineering. The preliminary results indicate that the systems proposed by MTI and STC are capable of meeting the DOE long-term goals when manufactured in quantities greater than 10,000 units per year.

- Stirling Thermal Motors (STM) has designed a solarized version of the STM4-120 kinematic Stirling with variable swashplate. A new design with 4 gas-fired heat pipes has been demonstrated at STM's facility with encouraging results. Full power testing on-sun is scheduled at DRTF during FY88.

- The University of Houston has developed techniques for separating photochemical reaction enhancements. These techniques have been used to show that significant photochemical enhancement occurs for heterogeneous catalytic chemical reactions.

- The University of Dayton investigated solar enhancement of photolytic and rapid heating reactions for use in the detoxification of hazardous wastes as well as to obtain a better understanding of the basic phenomena.

- Georgia Tech Research Institute has conducted 27 experiments on solar processing carbon fibers under various conditions. Results indicate that the degree of graphitization of selected carbon fibers has increased by the use of solar processing.

- The Closed Loop Efficiency Analysis (CLEA) facility was upgraded to accommodate higher reformer temperatures and increased methanation capacity, thus allowing for better selectivity in the reforming reaction, higher conversion in both the reformer and methanator, and higher overall efficiencies.

- Coking experiment to investigate carbon formation in the presence of catalysts has been completed. This included the thermogravimetric investigation of the initiation of coking in the CO_2/CH_4 reforming/methanation cycle as a function of temperature, gas composition, and catalyst.

- A contract was placed in early FY1987 with Resource Analysis International (RAI), Inc. to perform a detailed design of the Closed Loop Operations Experiment (CLOE) Phase I system. A decision was made to scale-down the design. The design will be less complex to operate and will still meet almost all of the original goals of the experiment.

c. Systems and Applications Technology Accomplishments

- The University of California, Berkeley, completed the first year of their three-year effort to evaluate the use of composite materials for stretched membranes.

- The University of Chicago finished the first year of their multi-year effort to evaluate optical concepts to achieve high solar flux through the use of secondary concentrators.

- Sandia completed development of dynamic simulation computer models for both a salt-in-tube and a Direct Absorption Receiver, and initiated validation of the salt-in-tube model.

- System studies were undertaken to enhance the state of theoretical and experimental knowledge of the DAR, which led to the selection of a configuration for a commercial-scale receiver.

- The Phase I conceptual designs for the Central Receiver Utility Studies have been completed. Initial designs are for 100 MWe plants (with eventual scale-up to 200 MWe) utilizing molten salt external receivers and stressed membrane heliostats.

- During FY87, Georgia Power Company (the operating utility company) completed a number of modifications to the Shenandoah Solar Total Energy Project (STEP), to expand and improve performance.*

- Participation in the Small Community Solar Experiments Cooperative Agreements continued. The SCSE #1 (Osage City, Kansas) parabolic dish module is being tested at the DRTF. Installation of the SCSE #2 (Molokai, Hawaii) module at the DRTF for testing was initiated.

- Phase II of the Central Engine Study, which examined central engine availability concepts in the 500 kW to 50 MW size range with operating temperatures between 400°C and 500°C has been completed.

- Development of a Shenandoah Total Energy Project (STEP) test program to provide baseline commercial operations information has been initiated. The program is approximately 50% complete.

- Participation in the Solar One 10 MWe Solar Thermal Pilot Plant Cooperative Agreement continued. The three-year utility power production phase has been completed.

- Installation of the Molten Salt Subsystem/Component Test Experiment (Category B) at the Central Receiver Test Facility (CRTF) has been completed, and operation initiated. The project is designed to resolve technical uncertainties which relate to the critical components of a molten salt central receiver plant: pumps, valves, and the receiver.

- Luz Industries completed construction of SEGS III and IV, and neared completion of SEGS V. All three plants have an output of 30 MWe, and are located at Kramer Junction, California. These additions bring the total output of the SEGS plants (SEGS I-V) to over 130 MWe.*

- LaJet Energy Company's Solarplant 1 completed another year of successful operation. The 4.9 MWe plant contains 700 of LaJet's low-cost 7.4 m diameter concentrators, and delivers energy to the San Diego Gas and Electric grid.*

d. Planning and Assessment Accomplishments

- The Solar Thermal Research Annual Conference was conducted at Golden, Colorado on February 18-20, 1987.

- The Solar Thermal Central Receiver and Distributed Receiver Annual Conference was conducted at Albuquerque, New Mexico on August 26-27, 1987.

---

*Non DOE Solar Thermal Technology funding.

IV. GOALS, OBJECTIVES, STRATEGIES, AND ACTIVITIES

A. Goals, Objectives, and Strategies

1. Office of Solar Heat Technologies

The **goal** of the Office of Solar Heat Technologies is to provide industry with a technology base that will ensure the supply of components and systems that convert solar energy into usable thermal energy at competitive costs.

The overall **objective** of the Office is to enhance the technical and economic feasibility of solar heat technologies for heating and cooling of buildings, agricultural and industrial applications, and generation of electricity. The management objective of the Office is to organize, plan, and direct the efforts of the two programs so that maximum overall benefits are obtained from the expenditure of Federal funds.

The **strategy** of the Office is to (a) support long-term, high risk research and development which industry cannot be expected to support, but which has high benefit potential; and (b) transfer research results to industry. The Office works in close cooperation with industry and institutions, including international organizations, to ensure that government-sponsored activities focus on research and development of concepts which have great potential payoff and do not duplicate efforts in the private sector. The Office balances the program among exploratory research and development; materials and components development; systems design, test and evaluation; and technology transfer activities.

2. Solar Buildings Technology Program

Goals: The program goal is to develop the technology base that will allow industry to develop solar energy products and designs for the buildings market which are reliable and economically competitive, and which can contribute significantly to building energy supplies.

Objectives:

- Provide industry with the information and techniques required to improve system performance and achieve acceptable equipment service life and reliability.

- Develop solar energy technologies that can be practically used to supply up to 80% of building space heating and hot water requirements and 60% of cooling requirements in residential buildings; and up to 60% of nonresidential heating, cooling, and daylighting energy requirements, at costs competitive with conventional technologies.

Strategy: In order to accomplish these goals and objectives, the program sponsors activities, in cooperation with the private sector, that offer the promise of dramatically improving the efficiency, cost, and applicability of solar buildings technologies in the long-term while providing design data from testing and analysis of state-of-the-art materials and systems useful to industry in the near-term. This strategy requires:

- A better understanding of how current solar technologies can effectively supply energy for building space conditioning, water heating, and lighting requirements through optimum integration with conventional systems.

- Innovation and advances in technology to achieve performance and cost-effectiveness necessary for the long-term viability of solar building technologies.

The near-term focus is to provide industry with useful results stemming from completed research. This will allow industry to improve the performance, cost, and durability of current components and systems.

The focus of the long-term R&D is on innovative technologies expected to have the greatest energy contribution potential in the residential and nonresidential building sectors. This includes R&D on new approaches for collection, conversion, storage, and delivery of solar energy using the building envelope and equipment. A "whole buildings" or systems perspective is employed by the program to ensure that an understanding of the interaction of new technologies with buildings and building systems is the basis for research direction and activities.

3. Solar Thermal Technology Program

Goals: The goals of the Solar Thermal Technology Program are to:

- Develop high-performance and reliable solar thermal systems and components that will be competitive for electric and process heat applications;
- Develop technology for new applications using concentrated solar energy; and
- Ensure technology exchange among universities, federal laboratory researchers, and the private sector.

The long-term energy cost goals for solar thermal technology, in levelized 1984 dollars, are 4-5¢ per kilowatt-hour for electricity and $9 per million BTU for process heat.

Objectives: The objective of the Solar Thermal Technology Program is to conduct (in cooperation with the private sector) the research necessary to establish solar thermal technologies as viable energy supply alternatives. A strong partnership between industry and the Federal government is critical to the success of the Solar Thermal Technology Program. Industry (suppliers and users) will benefit substantially from government-sponsored research and development of the technology. In return, industry's cooperation and capabilities will help to expedite the solutions to the problems facing solar thermal technology, and thus bring to the Nation a more secure energy future.

Strategy: The strategy of the Solar Thermal Technology Program is to pursue a program of goal-oriented, government-sponsored research and development balanced among fundamental materials and solar phenomena research, component and subsystem development, systems analysis, and system experiments. These activities are aimed primarily at specific component and system targets for electric and process heat applications. In addition, the program will continue the established technology transfer program and pursue cooperative efforts with industry to achieve early technology/market penetration.

B. FY 1988 Program Activities

1. Solar Buildings Technology Program -- FY 1988 Activities

In order to develop technologies that will supply energy for heating, cooling, and lighting residential and nonresidential buildings, the Solar Buildings Technology Program conducts research on materials and systems that will collect, store, manage, and distribute solar energy. Research activities under the program are broadly grouped into heating, cooling, daylighting, and solar systems integration program elements as indicated in Figure 2. Specific activities and milestones for each of the research areas and the Planning and Management program element are described below, and in Appendix I.

a. Heating Technology Research

The FY 1988 solar heating research activities will continue to emphasize 1) generic heating systems research; 2) high heat capacity thermal storage materials that can readily be combined with conventional building materials to increase performance and design flexibility; 3) systems level performance improvements through systems effectiveness; and 4) short-term monitoring techniques for predicting long-term performance. Specific FY 1988 activities that will be conducted are:

- Material and Subsystems Research

  Phase change materials (PCMs) incorporated into conventional gypsum wallboard will continue to be an important research topic. Heat storage capacity, reliability, durability, and safety characteristics of wallboard samples treated with various PCMs will be investigated along with fire retardant capabilities. Optimization of a neopentyl glycol solid state PCM will be performed in conjunction with DOE's Thermal Storage Program. Improved absorber and reflector coatings for integrated compound parabolic collectors will be evaluated and incorporated into advanced designs that will be developed during this fiscal year. The performance potential of glass absorbers and insert heat pipes will also be considered. Research on the scaled-up self-pumping collector will be concluded with the completion of seasonal tests.

- Heating Systems Research

  Generic heating system activities will focus on solar domestic hot water (DHW) applications in an effort to determine the most suitable configurations for widespread application. Up to four system types will be analyzed and candidate building/configurations will be identified for testing. Systems effectiveness research on the generic systems as well as other subsystems, components, and materials will continue. Short-term non-intrusive test procedures for the long-term evaluation of solar heating systems will be the subject of continuing research. Procedures such as those already developed for integral collector storage systems will be extended to the generic systems. Participation in IEA research on central solar heating plants with seasonal storage will continue including performance monitoring and evaluation of existing plants, as well as potential participation in a U.S. facility.

b. Cooling Technology Research

Desiccant cooling, and to a lesser degree, absorption cooling and passive cooling based on natural ventilation, evaporation, and radiation are the principal areas of program activity in FY 1988. This includes research on desiccants with improved heat and mass transfer properties, and higher performance dehumidifier designs. The absorption cooling effort is primarily directed at laboratory tests of low-cost open cycle concepts, and analytical work on advanced closed cycle absorption cycles and improved models. The passive cooling activities emphasize new approaches for reducing conventional cooling requirements for hot, humid climates. The specific FY 1988 activities that will be conducted are:

- Desiccants

  Desiccant materials research will continue to emphasize polymers and composites in an effort to identify materials with optimal characteristics or those which can be modified to achieve high performance. Another area of research will be dehumidifier geometries, especially the parallel passage designs which have shown promise in recent studies. In addition, other configurations such as hybrid desiccant/vapor compression will be investigated. The solid desiccant materials will be combined with improved heat and mass transfer dehumidifier designs to achieve high COPs (1.5) at input temperatures achievable by flat plate or compound parabolic collector (CPC) designs (130-170^{o}F). Analytical models will be developed in conjunction with these efforts to aid in understanding of dehumidifier and subsystem performance. Performance degradation resulting from desiccant contamination will also be studied.

- Building Dehumidification

  The emphasis on building dehumidification has grown out of research on cooling requirements in hot, humid climates. This research has shown that building dehumidification is the area requiring the greatest attention and one that could be addressed by new passive systems. FY 1988 research in this area will include building moisture research analysis, algorithms for moisture transport within residential buildings, investigation of moisture removal strategies, and the development of a residential test configuration.

- Absorption Cycles

  The issues of desiccant contamination mitigation and improved heat and mass transfer in open cycle absorption systems will be the focus of experimental and analytical studies during this fiscal year. Performance enhancing fluid additives and alternative low-cost absorbent fluids will also be investigated as well as a new falling film absorber design. Closed cycle absorption research will continue with past efforts to develop and apply computer models of advanced, high COP cycles.

c. Daylighting Technology Research

Daylighting activities will continue to emphasize research on materials exhibiting chromogenic properties (materials whose transmittance of sunlight changes as a function of temperature, level of solar radiation, or in response to electrical stimuli). Additionally, investigations are being conducted on materials and systems that can effectively pipe light into the interior of larger or multistory buildings. Atria will also be the subject of continuing research. The specific FY 1988 activities that will be conducted are:

- Perimeter Daylighting Systems

  Research on optical switching films will focus on scaling up the small-scale prototypes developed last year and on optimization of the individual films that make up the multilayer assembly. Short-term laboratory tests for predicting the long-term durability of the electrochromic devices will also be investigated. Another chromogenic material that will be investigated is a photochromic plastic material that changes transmittance depending on the amount of ultraviolet light absorbed. Research efforts on a high-transmittance, high thermal resistant glazing made of silica aerogel will be completed this year with the fabrication of 10" x 10" samples for industry evaluation. Advanced glazing technology options will be studied as part of a joint U.S./U.K. collaborative activity.

- Core Daylighting Systems

  Core Daylighting research efforts will include an investigation of the effects of various collector/light guide configurations on light transmission, evaluations of the performance of nonmechanical tracking systems, and a lens system which can accept sunlight over a wide range of directions and direct it over a smaller angular range. The objective of research in this area is to develop a light guide that can direct light up to distances of 100 feet with less than a

50% loss in light intensity. Research on holographic diffractive structures capable of directing light at a fixed angle regardless of the position of the sun has resulted in a prototype system made from an expensive silver halide emulsion. Current efforts will focus on developing a full-scale prototype using a low-cost process. Atria research during this fiscal year will involve the evaluation of various design and glazing strategies and the analysis of field performance data. This will be performed as part of a joint U.S./U.K. bilateral agreement and task XI of the IEA Solar Heating and Cooling Agreement.

d. Solar Systems Integration Research

Solar systems integration activities are focused on optimizing the use of solar energy within the building by using appropriate combinations of various solar heating, cooling, and daylighting technologies with conventional building elements. By analyzing the expected performance of entire buildings which use the new materials, and systems emerging from research on heating, cooling, and daylighting technologies, it will be possible to determine their relevancy to the widest cross-section of buildings and their potential impacts on the program's energy goals and objectives. In FY 1988, activities will involve the development of a simplified analysis methology for nonresidential solar buildings, verification of design tools, the development of builder guidelines, and the improvement of the short-term monitoring methodology to predict long-term thermal performance. The specific FY 1988 activities that will be conducted are:

- Analysis

  A feasibility study of a simplified energy performance model will continue. This model employs a modular approach using functional spaces (e.g. kitchens, offices, lobby areas) to assess a buildings energy performance. Research on a novel method to enhance room-to-room passive energy transfer will be concluded during this fiscal year. This method employs a heat absorbing window coupled with distributed thermal storage. This effort will examine the impacts of low-e coatings, storage location, and room reflectivity on heat transfer effectiveness and overall performance of the system. A study of the effects of passive cooling strategies coupled with conventional cooling or cool storage on overall cooling load will be concluded this year.

- Design Tools

  Research efforts in this area during FY 1988 will concentrate on guides to be used by the design community and the builder community. Design Guides for residential passive solar heating and cooling, as well as guidelines for nonresidential ventilation cooling, based on the accumulated program experience will be prepared. Builder Guidelines will be revised based on the requirements of the building community. The software required to generate the site-specific guidelines will be completed and made available to the industry. In addition, a microcomputer-based expert system based on the builder guidelines will be developed to simplify use of the guidelines as well as enhance the guidelines' capabilities. The development of a procedure for verifying the accuracy and range of application of design tools will also be continued in FY 1988.

- Performance Monitoring

  The focus of efforts in this area will be on the validation of short-term monitoring methods that can be used to predict long-term performance of residential buildings, and on their extension to nonresidential buildings. This will be conducted in collaboration with the NAHB/National Research Center.

e. Planning and Management

Planning and management activities include the development of annual and multi-year research plans, improvements to the research planning process, and technology transfer. A general description of how the Solar Buildings Technology Program is managed and implemented is provided in Appendix I.

Planning and Management activities in FY 1988 will include the finalization of a Multi-Year Program Plan (MYPP) for the period FY 1988-1992. Additionally, individual research plans for the Solar Heating, Solar Cooling, Daylighting, and Solar Systems Integration areas will be completed. These plans will outline specific technology objectives, research paths, and schedules. Other planning and management activities include cooperative efforts with industry on prior efforts and new strategies and support in carrying out U.S. commitments under various IEA and bilateral agreements.

2. Solar Thermal Technology Program -- FY 1988 Activities

The Solar Thermal Technology Program sponsors research in many areas in order to achieve its goals of providing viable electricity and industrial process heat options which will be competitive in the 1990's. Research activities are grouped into the areas of Collection, Conversion, and Systems and Applications. A description of the research activities in each of these areas is given below as well as in Appendix II.

a. Collection Technology Research

The objective of this program element is to identify and characterize collection materials and components suitable for stable long-life performance in concentrating solar applications. Concentrating solar thermal technologies have great potential for cost-effective energy production. To realize this potential more fully, low-cost/light-weight reflectors, high-temperature receivers, and high-performance concentrators must be developed. The specific FY 1988 activities that will be conducted are:

- Optical Materials

  Research in optical materials includes identification and characterization of reflecting materials and substrates; fundamental evaluation of the failure mechanisms of optical surfaces, degradation mechanisms in polymers, surface treatments for and surface characteristics of optical materials; and research on promising new optical materials and concepts.

  One of the most important areas of current research emphasizes development of silvered polymer films that can reduce the cost of reflective surfaces while maintaining the required performance. This leads to reduced costs of supporting structures by eliminating the higher weight and poor impact resistance of glass mirrors. Other benefits accrue from the improved ease of handling, fabrication, and installation. Silver/polymer materials have been demonstrated with initial optical properties which exceed program goals (90% reflectance into a 2 mrad half-cone acceptance angle). Current research focuses on achieving a five year life goal for these materials, and understanding and preventing environmental degradation.

  Another area of research deals with evaluation of the material, structural, and fabrication issues associated with various composite membrane and structural support elements for solar concentrators. Work is also continuing on optimization of the sol-gel process for stainless steel structural mirrors, an alternative to silver/polymer membranes for lightweight, low-cost reflectors.

- Soiling and Cleaning

  Eliminating soil from reflecting elements is a necessary condition for optimum performance of solar reflectors. Therefore, research will continue to evaluate soiling and cleaning mechanisms in reflective materials in order to find ways to reduce performance degradation associated with soiling.

- Concentrators

  Concentrators collect, concentrate, and transmit incident sunlight to a receiver where it is converted to thermal energy. Concentrators typically constitute about one-third to one-half of the total cost of a solar thermal system. Reducing the weight and cost of concentrators, while maintaining the required level of strength and optical performance, has been a continuing objective of the program. Several approaches are being pursued to achieve the concentrator performance goals. These include the improvement of the current glass mirror concentrators, development of innovative concentrators, and development of low-cost concentrators utilizing silvered polymer membranes.

  Research, testing, and evaluation of low-cost advanced optical concentrators, in cooperation with industry, will be continued and expanded in scope. In FY 1988, work will continue on heliostat design and development for central receiver systems including the completion of testing of prototype stressed membrane heliostats and large area glass metal heliostats, and construction and testing of a low-cost heliostat drive mechanism. Cost effective cleaning systems for large-area glass/metal and stressed membrane heliostats will also be studied. For parabolic dish concentrator research, testing will be completed on an innovative concentrator initiated in prior years, and increasing emphasis will be placed on membrane concentrator research. In particular, work will continue on development of large facet stretched membrane dishes and thin foil membranes. Detailed designs of membrane dishes will be inducted in FY 1988 by two industrial contractors. Advanced concentrator research will be conducted to evaluate concepts such as mesh membranes, polymer composite membrane dishes, and secondary concentrators.

- Receivers

  Receivers are a key feature in all types of solar thermal systems, since they convert the concentrated sunlight to thermal energy. In a parabolic trough system, the receiver is a long tube located along the focal line of the trough concentrator. A heat transfer fluid, usually a synthetic oil in the higher temperature systems, transfers the heat to the point of use. In a parabolic dish system, a compact receiver is located at the focal point of the dish and provides the heat input to a central or dish-mounted engine/generator combination to produce electricity, or the heat output from the parabolic dish can be used directly in industrial processes. In a central receiver system, a field of heliostats reflects the sunlight onto one centrally-located receiver which transfers the absorbed thermal energy to a generator for the production of electricity or process heat, or for fuels and chemicals applications.

  Receiver R&D for central receiver systems is focused on finding the best cost/performance subsystems and systems for applications up to 600°C (1100°F). This temperature range is a main element in the near-term technology development thrust. Receivers using molten nitrate salt are under study to improve the reliability and decrease fabrication cost of molten salt receiver configurations. Appropriate containment materials, compatible with the heat transfer media at the required temperatures, are also being identified and evaluated. A major activity for FY 1988 will include deciding whether to expand testing of an advanced 5MWt molten salt receiver under the Molten Salt Subsystem/Component (Category B) Experiment.

Advanced receiver research is focused on identifying and verifying the technical feasibility of new receiver concepts; obtaining fundamental data on receiver materials and mechanisms; and characterizing new components, materials, and subsystems. Research activities planned for FY 1988 will focus on further development of the direct absorption receiver (DAR) concept, which has great potential for high-temperature and high-flux applications. Continued DAR development will include investigation of the potential for reactive carbon dopants; performance, structural, and thermal analysis of conceptual commercial DAR designs; exploration of the potential of using a multi-layer wire mesh absorber substrate instead of dopants; completion of the Sandia small-scale water flow testing; initiation of full-scale water flow testing; and the 2 MWt solar test at the CRTF.

The reflux receiver is basically a heat pipe using solar flux as the heat input. The working fluid, which is sodium in current designs, flows back to the heat source by gravity and capillary action. The term "reflux" refers to this flowing back. Analysis of preliminary designs indicates that simple, low-cost, reliable, and efficient reflux receivers are possible with applications for a variety of heat engines and transport options. This concept will be developed further during FY 1988 through evaluation of the "pool boiler" and sintered powder wick reflux configurations proposed in the free-piston Stirling engine preliminary design and in tests using a gas-solar hybrid of the STM4-120 Stirling engine. Additional work will be performed to continue development of receiver design computer codes and experimental devices for the measurement of flux and temperatures in a receiver.

b. Conversion Technology Research

The objective of this program element is to identify processes and components to convert thermal energy into electricity or other usable energy forms such as fuels and chemicals. It also includes thermal or thermochemical processes for transporting energy, and thermal energy storage. The specific FY 1988 activities that will be conducted are:

- Heat Engines

  Heat engines convert thermal energy into mechanical work. In a parabolic dish electric system, the engine drives a generator to produce electrical power. Organic Rankine and Stirling cycle engines have received continuing solar thermal program support because of their suitability for dish electric module applications. In recent years, experimental work has also been conducted in connection with the development of thermoelectrochemical converters, such as the regenerative thermoelectric converter (RTEC), which employ a direct conversion process for converting thermal energy to electricity.

  Stirling engine development for dish electric systems will include work on the variable swashplate design and the free-piston Stirling engine (which has the potential of offering highly reliable and maintenance-free operation). In FY 1988 initial testing will be conducted on a solarized STM4-120 kinematic Stirling engine and cooperative work will continue with NASA on detailed design and fabrication of a solarized free-piston Stirling engine.

  In the area of thermoelectrochemical conversion, efforts will be focused on the RTEC concept. During FY 1988, RTEC research will include development of the solid electrolyte/electrode system, continued development of the thermal regenerator, system assessment relative to other conversion techniques, and studies on heat transfer and fluid dynamics associated with chemical/thermal regeneration of RTEC working fluid using concentrated solar flux. Thermochemical experiments designed to provide the experimental and theoretical basis for the design of an RTEC receiver/regenerator, and materials research necessary to identify feasible containment materials for fabrication of the receiver/regenerator will also be conducted.

- Direct Conversion Devices

  This area supports research on solar unique or solar beneficial chemical reactions, photoenhanced catalysis, solar detoxification of hazardous wastes, and high flux materials effects. The purpose of photo-assisted reactions research is to determine how to use the entire solar spectrum effectively, with emphasis on using the most energetic portion to drive a chemical conversion to produce species that beneficially affect the conversion of the rest of the spectrum. This research could result in the development of processes which are uniquely suited to solar thermal applications. Research into solar detoxification of hazardous wastes is aimed at defining the beneficial effects of employing solar thermal energy to detoxify hazardous waste using photolytic enhancements which can be achieved through the application of high solar fluxes. Photoenhanced catalysis research will study possible enhancement of heterogeneous catalytic reactions under high flux solar irradiation at elevated temperatures. High flux materials effects research will identify and analyze the effects of concentrated solar radiation on materials in order to understand possible ways to increase the durability of materials as well as utilize high solar flux effects in other beneficial ways.

- Transport and Storage

  Thermal energy transport and storage is important in all systems involving conversion of solar radiation to thermal energy because of the intermittent nature of sunlight falling on the collecting surfaces. Thermal energy storage can smooth out transient periods of low insolation and extend the period of power operation. It can also permit taking advantage of load-shifting economics. Storage is particularly important for central receiver systems and would permit capacity credits for electricity produced from solar thermal systems. Solar thermal energy transport systems require high efficiencies in order to retain high total system efficiencies.

  In FY 1988 efforts will be devoted to the continued development and demonstration of components in molten salt loops for central receiver systems. This development will be carried out through continuation of full-scale testing of molten salt pump and valve loops under the Molten Salt Subsystem/Component Experiment. Research will also be conducted to characterize the thermal, physical, and chemical properties of salt/water and ternary salt mixtures which have lower boiling points than currently used nitrate salts. Use of these mixtures could reduce parasitic losses associated with trace heating to prevent freezing of molten salts.

c. Systems and Applications Technology

The objective of this program element is the development of system studies and parametric analysis at an early stage to assess the economic potential of alternate concepts, and to define critical technology and component issues. This research effort includes the evaluation of existing designs, components, subsystems and systems. Support for small-scale engineering experiments and pilot plants are included as necessary to achieve program goals. The specific FY 1988 activities to be conducted are:

- Innovative Concepts and Applications/Small Business Innovation Research (SBIR)

  The objective of this area is the investigation of innovative concepts and new applications which have the potential of meeting long-range program goals and defining new applications for solar thermal technology. Priority is given to concepts which, although high risk, could significantly reduce the cost of systems or components. Efforts are in progress to involve a wide range of researchers outside of the national laboratories in this endeavor. Work on the use of composite materials for stretched membranes being conducted at the University of California, Berkeley and development of an optical concept by the University of Chicago to achieve very high solar flux concentrations will be continued in FY 1988.

The Small Business Innovation Research (SBIR) program is supported by DOE to encourage high-quality research or R&D proposals on advanced concepts concerning important energy-related, scientific or engineering problems and opportunities that could lead to significant public benefit if the research is successful. Solar thermal SBIR projects in the areas of advanced concentrators and the direct use of concentrated solar flux will be continued in FY 1988.

- Balance of Plant

This task will address research on the non-solar components necessary to construct, maintain, and operate a complete solar thermal system. Conventional balance of plant equipment constitutes a significant portion of solar thermal system costs. The primary goals of this task are the reduction of balance of plant capital costs, minimization of parasitic and auxiliary power requirements, and reduction of operation and maintenance costs.

The objective of this research task is to minimize the risk and expense associated with the operation and maintenance of solar thermal systems, principally through the development of innovative maintenance approaches and control systems that would allow for unattended operation. In FY 1988, a dynamic simulator developed in FY 1987 will be extended to mimic a commercial scale central receiver power plant as defined by the utility study. The simulator will be used to evaluate a variety of control and operating strategies to maximize the output of the commercial plant.

- Central Receiver Systems

Central receiver systems research includes the development of designs, the analysis of system parameters, and the experimental testing and evaluation of complete systems. Operation of the Central Receiver Test Facility (CRTF) is also conducted under this task. The integration of components and subsystems into a complete system is necessary to properly analyze the cost and performance tradeoffs and to identify critical technology development requirements. The experimental testing of groups of components provides valuable data on subsystem interfaces and performance in a solar environment.

Several system studies are underway that involve applications of solar central receiver technology. They are directed at understanding various design and economic tradeoffs in the context of actual data from operating central receiver systems. These studies will indicate optimum techniques for reducing the delivered energy cost for central receiver systems while improving performance and reliability and decreasing risk.

- Distributed Receiver Systems

The objective of this activity is the development of distributed receiver solar energy systems that can produce thermal energy for electricity and heat applications at costs competitive with conventional energy sources. This task provides the systems engineering and analytical work needed to support the distributed receiver technology. Research being pursued includes system requirements, constraints, trade-off studies, and economics. It also provides conceptual (in some cases, preliminary or definitive) designs of systems and sub-systems. Operation and maintenance of the Distributed Receiver Test Facility (DRTF) is also conducted under this task.

The main emphasis of this research task is to model dish electric systems featuring Stirling engines and to evaluate modifications and upgrades made at the Solar Total Energy Project (STEP), the world's largest solar plant using cogeneration concept of energy production for an industrial application.

- System Experiments

System experiments provide data on capital cost, performance, and operations and maintenance of complete solar thermal systems. The system experiments are conducted with major participation from solar equipment manufacturers and potential users. These experiments lead to the establishment of technical feasibility, the development of a cost and performance data base, technology exchange and discussions that can help in private sector decisions, and the identification of future research and development needs.

Several major system experiments are now on-line. Operations and maintenance data are being evaluated from the Solar One 10 MWe Solar Central Receiver Pilot Plant near Barstow, California; the 3 MWt parabolic dish total energy (cogeneration) plant at Shenandoah, Georgia; the LaJet 4.9 MWe parabolic dish facility near Warner Springs, California*; and the large Luz parabolic trough electricity generation plants at Daggett and Kramer Junction, California*. Daily operations at the Barstow central receiver experiment and at the Shenandoah parabolic dish facility are now the responsibility of their respective utility users, Southern California Edison and Georgia Power. During FY 1988, Solar One will be operated by Southern California Edison in a semi-commercial mode (5 days per week) with a minimum of personnel. Luz trough systems SEGS I-V are currently on-line, generating nearly 135 MWe, and Luz has begun construction of additional 30 MWe plants at the Kramer Junction site.

In addition, two experiments using parabolic dish technology are being conducted to evaluate solar electric plants in small community/utility environments, one to be located at Osage City, Kansas (SCSE #1 - 100KWe), and the other at Molokai, Hawaii (SCSE #2 - 250 kWe). To establish system feasibility and to identify the operations and maintenance costs of these experiments, several years of operating experience will be accumulated for all the plants' operating modes. The plants' system and component performance will also be evaluated. During FY 1988, SCSE #1 module verification with the new LaJet concentrator will be completed. The SCSE #2 module verification is scheduled to begin at the DRTF in January 1988 and the Molokai site construction is scheduled to begin in June 1988.

d. Planning and Assessment

The objective of this activity is to conduct program integration, assessment, and comparative analysis, as well as specific technology transfer activities such as program documentation, workshops, and periodic contractor review meetings. Program planning and support activities in FY 1988 will include continuing efforts to identify near-term high-value opportunities for solar thermal technology such as solar cleanup of contaminated water supplies and international opportunities. In addition, coordination with industry and state government solar thermal activities to leverage DOE program efforts to the maximum practical extent will continue.

---

*Non-DOE Solar Thermal Technology Funding.

3. International Support--FY 1988 Activities

International activities comprise an important component of the Solar Heat Technologies Program. These activities are conducted primarily through the collaborative R&D agreements of the International Energy Agency (IEA) and a small number of bilateral agreements. Involvement in these projects affords the opportunity to leverage research funds, to augment the DOE research program, to gain access to experience and expertise in other countries, and to conduct projects and experiments which could not be funded by the U.S. alone. The labs, universities and private sector organizations which play important roles in the overall Solar Heat program are also participants in the international R&D projects, and Solar Heat program managers are responsible for managing and giving policy direction to U.S. participation. As a result, the international projects are supportive of and generally well-integrated into the Solar Heat Technologies Program. Tables I and II summarize major FY1988 international activities receiving program support.

TABLE I. INTERNATIONAL ACTIVITIES - SOLAR BUILDINGS TECHNOLOGY

- IEA Solar Heating and Cooling Program

IEA TASK	U.S. PARTICIPANTS	PROGRAM AREA
3: Solar Collector Testing	Arizona State Univ.	Heating Technology Research
6: Evacuated Tubular Collector Systems Central Solar Heating Plants	Colorado State Univ., CBY Associates	Heating and Cooling Technology Research, Heating Technology Research
8: Passive Solar Residences	Architectural Energy Corp. (AEC); SERI; Burt, Hill, Kosar, Rittleman Assoc. (BHKR)	Heating Technology and Systems Integration
10: Solar Materials R&D	Lawrence Berkeley Labs (LBL), SERI	Daylighting Technology Research
11: Passive Solar Commercial Buildings	BHKR	Daylighting Technology and Systems Integration

- U.S./U.K. Passive Bilateral Agreement

ACTIVITY	U.S. PARTICIPANTS	PROGRAM AREA
o Application of U.S. Analysis Methodology to U.K. commercial building	LBL	Systems Integration

TABLE I. INTERNATIONAL ACTIVITIES - SOLAR BUILDINGS TECHNOLOGY (Cont'd)

ACTIVITY	U.S. PARTICIPANTS	PROGRAM AREA
o Joint workshop on atria and daylighting research	LBL; Burt, Hill, Stinson, Cappelli (BHSC); AEC	Daylighting Technology Research
o Fenestration 2000 research on advanced glazing materials	LBL, Libby-Owens Ford (LOF)	Daylighting Technology Research

TABLE II. INTERNATIONAL ACTIVITIES - SOLAR THERMAL TECHNOLOGY

- IEA Small Solar Power System (SSPS) Agreement

IEA TASK	PARTICIPANTS	PROGRAM AREA
3: High-Temperature Receiver Technology	Sandia, SERI	Collection Technology Research
4: High-Temperature Thermal Storage	Sandia, SERI	Central Receiver Systems
5: Solar Fuels, Chemical and Energy Transport	Sandia	Conversion Technology Research
6: Long-Term Fuels and Chemicals	SERI	Conversion Technology Research

- U.S./Israel Bilateral Agreement*

ACTIVITY	PARTICIPANTS	PROGRAM AREA
o Testing of U.S. ceramic receiver in test facility in Israel	Sandia	Collection Technology Research
o Hardware testing and other experiments to advance the understanding of solar-driven thermochemical processes	Sandia	Conversion Technology Research

*Solar thermal research is being conducted under Annex 10 (Simulation and Analysis of High Temperature Receivers and Thermochemical Processes) of the U.S./Israel Energy R&D Agreement.

C. Key Milestones

FY 1988 Key Milestones for the Solar Buildings and Solar Thermal Technology Program areas are shown in Appendices I and II, respectively.

V. MANAGEMENT APPROACH

In this section, the management approach used by the Office of Solar Heat Technologies is described in terms of headquarters and field organization roles, program planning activities and documents, reporting and control procedures, and program evaluation techniques.

A. Organization

The Director of the Office of Solar Heat Technologies reports to the Deputy Assistant Secretary for Renewable Energy who, in turn, reports to the Assistant Secretary for Conservation and Renewable Energy. This organization structure is shown in Figure 1.

1. DOE Headquarters

At DOE Headquarters, The Office of Solar Heat Technologies organization has three management levels: the Office Director, Division Director, and Program Manager. Each plays an important role in program execution and management. Major activities for the DOE Headquarters staff are to:

- Develop an integrated technology strategy and eliminate duplicative program activities.
- Prepare and submit annual budgets and plans which provide necessary program information for DOE planning, programming, and budgeting documents.
- Make policy recommendations concerning:
  - Program direction, balance, and evaluation
  - Budgets and funding allocations
  - Personnel and administrative issues.
- Conduct periodic Office-level program management reviews and establish procedures for program management and integration among technologies and operating divisions.
- Provide planning guidance to program managers and field organizations regarding preparation of inputs to Field Task Proposals (FTPs).
- Review and approve Annual Operating Plans and FTPs; assure that projects are integrated into programs and periodically track progress toward program objectives.
- Evaluate activities with respect to program goals and allocated budgets.
- Evaluate field organization performance in terms of stated goals.
- Maintain informal contacts with field personnel for transfer of technical and program management information.

2. Field Management

The Office of Solar Heat Technologies research program is administered through a field organization that consists of DOE operations offices, national laboratories, and industry and university contractors. The DOE Operations Offices' primary responsibilities are to manage contracts with industry and universities and to dispense funds to laboratories, universities, and industry contractors in accordance with approved plans from DOE Headquarters. The national laboratories conduct R&D and subcontract with universities or industry as required to carry out their research responsibilities. In order to simplify program structure, minimize reporting requirements, and maximize coordination, the Office of Solar Heat Technologies has designated specific laboratories as program centers, with responsibilities in specific technology/program areas.

The Office of Solar Heat Technologies field structure continues as considerably streamlined in FY 1988 to reflect the recent reduction in the number of operating Divisions from 3 to 2, as well as reduced program budgets. One field office and several laboratories have been phased out, and program operations have been strengthened by the establishment of two Technology Program Integration (TPI) Offices at the Solar Energy Research Institute. Although housed at SERI, the TPIs act independently from the SERI research program. They have been assigned responsibilities for annual and multiyear program planning, conducting topical review meetings and systems analyses to support the planning process, and coordinating laboratory and industry research activities. Designated staff from the program centers have been assigned to work with the SERI/TPIs to ensure the effectiveness of this planning and coordination function. Figure 2 illustrates the overall Office of Solar Heat Technologies field organization structure.

B. Planning, Reporting, and Control

1. Program Planning

Program plans are typically embodied in two different kinds of documents: Multi-Year Program Plans (MYPPs), that describe Federal near-term plans, and Annual Operating Plans (AOPs), which focus on a single year. A Field Task Proposal (FTP) is used to define individual laboratory projects and serve as the basis for much of each AOP. The content of these documents is outlined in this section.

MYPP

The MYPP delineates goals, objectives, strategies, and overall program direction for a period of five years. The MYPP is usually updated annually to reflect technical accomplishments, policy changes, and budget guidance. Development of these plans involves extensive meetings with industry and government researchers as part of a structured program planning process. The MYPP serves to guide research activities for the program area beyond the scope of the AOP.

AOP

AOPs are the primary tools used to plan and manage work in the current fiscal year. They contain information on management, technical programs, and resource allocations. AOPs are developed iteratively and in conjunction with field personnel. AOPs typically are prepared by several organizational levels; at Headquarters by offices and programs and in the field by lead centers.

FTP

The FTP is the fundamental document describing work planned at DOE National Laboratories and SERI and once approved, constitutes a "contractual agreement" between a field organization and Headquarters.

The FTP sets forth program objectives as discrete, visible, manageable tasks and projects. FTPs are submitted to Headquarters program offices for approval and they provide a basis for subsequent review, monitoring, and control of approved efforts.

2. Reporting and Control

Several mechanisms are employed at the office level for program control including weekly staff meetings, bi-monthly program reviews, quarterly field management review meetings, and a field reporting system.

Bi-Monthly Program Review Meetings, based on the AOPs, are the primary vehicle for oversight of program activities. Quarterly Field Management Review meetings provide a forum for consideration of major issues affecting the field.

Detailed written status information is provided periodically by the field reporting system. It consists of a variety of reports prepared and submitted by the contractors and field organizations. These include weekly significant events and quarterly progress reports. Technical accomplishments and cost and milestone status are reported against the plan represented in a contract, FTP, or AOP.

Control is also facilitated by formal procedures instituted for the review and approval of deliverables and for any changes by the Office of Solar Heat Technologies. Deliverables, principally reports, are accepted only after the reports have gone through peer review by independent technical experts and final approval by the program manager and division director. Changes in the funding level of an R&D effort, or slippages of milestones, require approval at various organizational levels in Headquarters by program managers, division directors and the office director. The current organizational structure of the Office of Solar Heat Technologies is shown in Figures 1 and 2.

VI. RESOURCES/FY 1988 FUNDING

The current FY 1988 budget for the Office of Solar Heat Technologies is $22.4 Million. These funds are allocated by program as indicated in Figure 3. This figure also displays historical funding levels. Funding distribution of the FY 1988 budget by program, major program element, and recipient is depicted in Figure 4. Funding obligations for each of the divisions are broken down in Figure 5. Major industry and university participants are given in Figure 6. Additional funding details, particularly with regard to procurement and obligation plans, can be found in the program AOPs, Appendices I and II.

Figure 1.
ORGANIZATION OF CONSERVATION AND RENEWABLE ENERGY

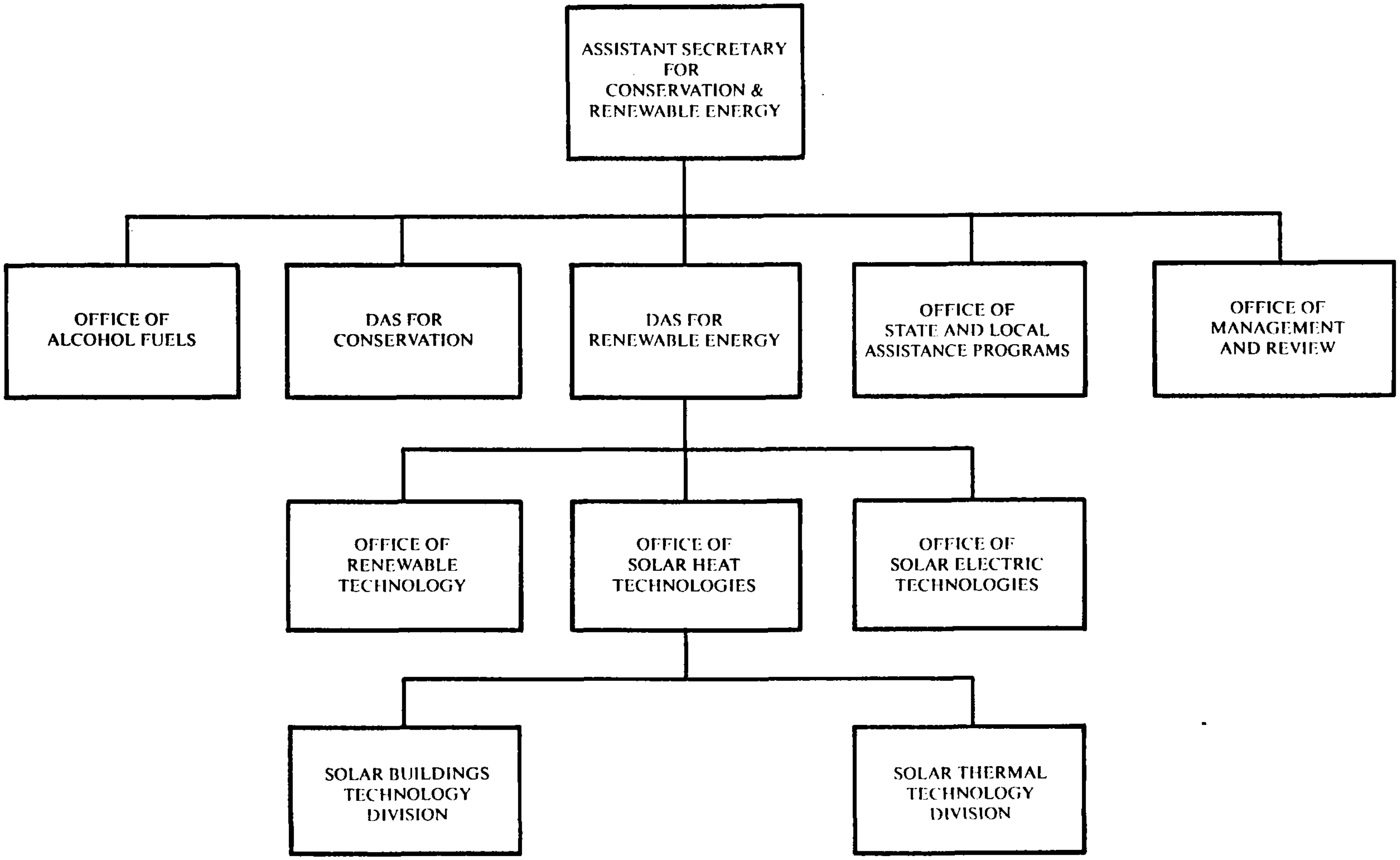


Figure 2.

ORGANIZATION OF SOLAR HEAT TECHNOLOGIES FIELD ORGANIZATION AND WORK BREAKDOWN STRUCTURE

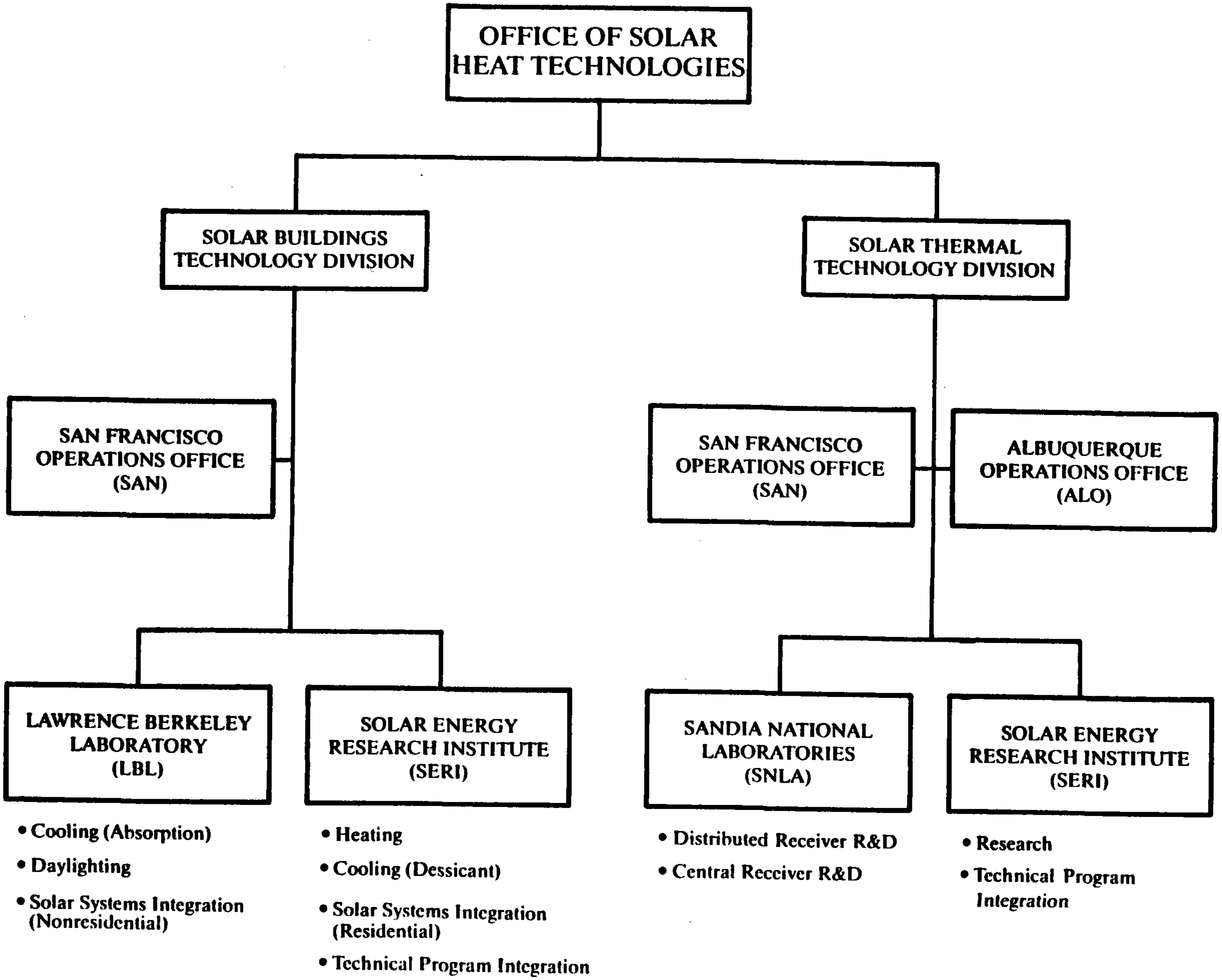


Figure 3.

OFFICE OF SOLAR HEAT TECHNOLOGIES RESOURCES BY PROGRAM

(Dollars in Millions)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
SOLAR BUILDINGS	12.5	52.7	98.0	99.1	114.3	98.0	71.6	23.1	12.5	16.5	10.0	8.2	5.9	5.4
SOLAR THERMAL	15.5	39.3	75.6	114.4	109.4	143.2	138.3	53.0	44.4	43.2	34.9	26.2	22.9	17.0

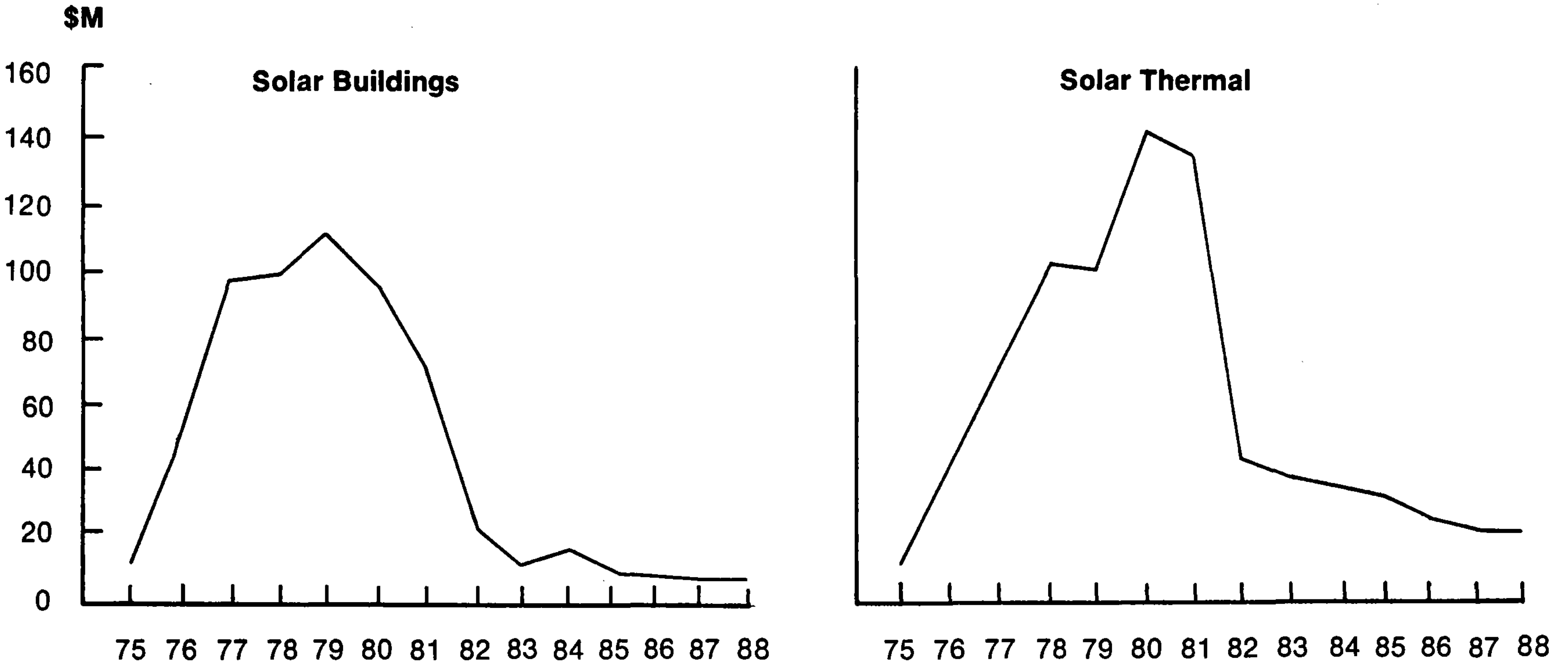


Figure 4.

OFFICE OF SOLAR HEAT TECHNOLOGIES
FY 1988 FUNDING BY PROGRAM ELEMENT AND RECIPIENT

(Dollars in Thousands)

PROGRAM ELEMENT			FUNDING ORGANIZATION			
	HQ	SAN	SERI	SNL	LBL	TOTAL
SOLAR BUILDINGS TECHNOLOGY PROGRAM						
Solar Heating Technology	--	333	760		--	1,093
Solar Cooling Technology	--	660	300		90	1,050
Daylighting Technology	--	562	100		610	1,272
Solar Systems Integration	--	515	571		95	1,181
Planning and Management	274	220	160		--	654
Capital Equipment	--	110	18		22	150
SUBTOTAL	274	2,400	1,909		817	5,400
SOLAR THERMAL TECHNOLOGY PROGRAM						
Collection Technology	--	--	3,440	6,520		9,960
Conversion Technology	--	--	1,070	1,450		2,520
Systems & Application Technology	210	250	150	3,060		3,670
Planning & Assessment	400	--	400	--		800
Capital Equipment	88	--	--	--		88
SUBTOTAL	698	250	5,060	11,030		17,038
TOTAL	972	2,650	6,969	11,030	817	22,438

Figure 5.

OFFICE OF SOLAR HEAT TECHNOLOGIES FUNDING OBLIGATIONS DISTRIBUTION

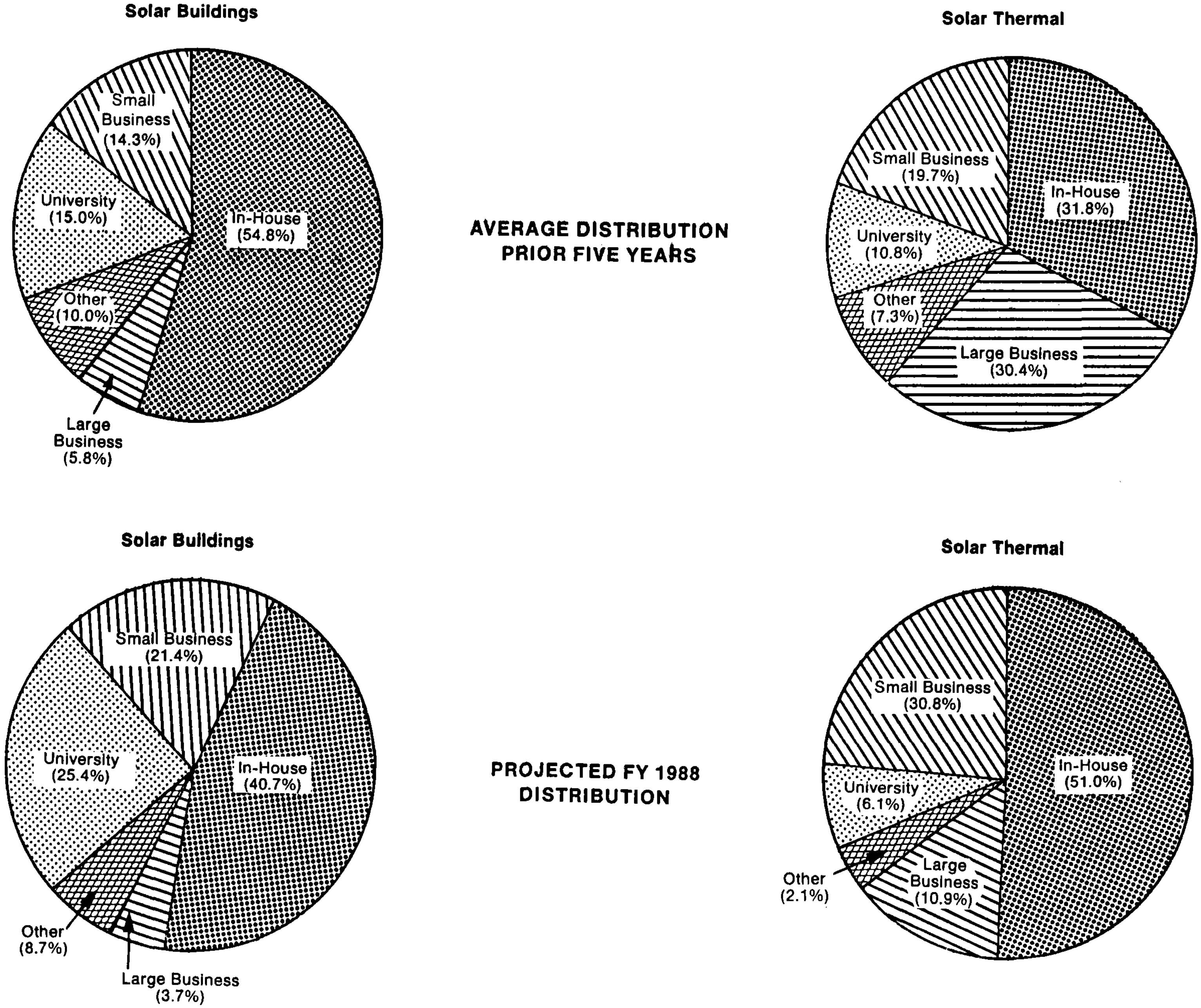


Figure 6.

OFFICE OF SOLAR HEAT TECHNOLOGIES MAJOR INDUSTRY/UNIVERSITY PARTICIPANTS

SOLAR BUILDINGS

- Industry
  - American Society/Heating Refrigerating and Air Conditioning Engineers
  - American National Standards Institute
  - American Consulting Engineers Council
  - Honeywell
  - EIC Laborabories
  - Solar Energy Industries Association
  - Passive Solar Industry Council
  - National Association of Home Builders/ Research Foundation
  - Americal Optical
  - Florida Solar Energy Center
  - Lighting Sciences, Inc.

- Architects & Engineers
  - AERG
  - American Institute of Architects/ Research Corp.
  - ASHRAE
  - Architectural Energy Corporation
  - Burt, Hill, Kosar, Rittleman Associates
  - EA-Mueller, Inc.

- Universities
  - Tufts
  - Dayton
  - Wisconsin
  - Colorado State
  - Arizona State
  - Chicago
  - Nevada

SOLAR THERMAL

- Industry/A&E
  - Solar Power Engineering Co.
  - McDonnell Douglas
  - Rockwell International (Sanders)
  - Babcock & Wilcox
  - Barber-Nichols Engineering
  - Acurex
  - Solar Kinetics, Inc.
  - Foster Wheeler Solar
  - LaJet Energy Company
  - SAIC
  - Advanced Thermal Systems
  - EG&G
  - Peerless-Winsmith, Inc.
  - Power Kinetics, Inc.
  - Bechtel
  - Black & Veatch
  - Stirling Technology Company
  - Resource Analysis Intl, Inc.
  - Hughes Aircraft Company
  - Luz Engineering Corp.
  - Polydyne, Inc.
  - 3M Company
  - Custom Engineering
  - Entech
  - Technadyne Engineering
  - Stirling Thermal Motors
  - Mechanical Tech., Inc.
  - WG Associates
  - ARCO Solar

- Universities
  - Colorado State
  - Denver
  - Arizona
  - Chicago
  - Akron
  - New Mexico State
  - Utah
  - Arkansas
  - Pennsylvania
  - Wisconsin
  - Hawaii
  - New Hampshire
  - Pittsburgh
  - New Mexico
  - California
  - Dayton
  - Georgia Tech
  - Nevada
  - Houston
  - Cal Tech

- Utilities and Institutes
  - Georgia Power
  - Southern California Edison
  - Arizona Public Service
  - Pacific Gas & Electric
  - Public Service Co. of New Mexico
  - San Diego Gas & Electric
  - Electric Power Research Institute
  - Southern Research Institute
  - Missouri Research Laboratory (Ewing)
  - El Paso Electric Company

APPENDIX I

FY [illegible] ANNUAL OPERATING PLAN

SOLAR BUILDINGS TECHNOLOGY PROGRAM

FISCAL YEAR 1988
ANNUAL OPERATING PLAN
SOLAR BUILDINGS TECHNOLOGY PROGRAM

July 1988

U.S. DEPARTMENT OF ENERGY
1000 Independence Avenue, S.W.
Washington, DC 20585

FISCAL YEAR 1988
ANNUAL OPERATING PLAN
SOLAR BUILDINGS TECHNOLOGY PROGRAM

July 1988

U.S. DEPARTMENT OF ENERGY
1000 Independence Avenue, S.W.
Washington, DC 20585

Table of Contents

1. INTRODUCTION AND OVERVIEW

1.1 The Solar Buildings Technology Program

The Department of Energy's (DOE) Solar Buildings Technology Program conducts research to develop technologies that will supply energy for heating, cooling and lighting in residential and nonresidential buildings. The program: (1) undertakes the research needed to develop advanced, innovative materials and systems appropriate for collecting, storing, managing, and distributing solar energy in both new and existing buildings, and (2) develops and makes available to industry the knowledge required to facilitate adoption of solar building technologies. As an integral part of identifying and developing promising new materials and systems, the program establishes how such advanced solar technologies can be economically integrated into a building as stand alone systems or in combination with conventional heating, cooling, and lighting systems.

1.2 Annual Operating Plan

The Annual Operating Plan (AOP) sets forth the basis for managing the Fiscal Year (FY) 1988 Solar Buildings Technology Program. It describes the program's structure and contains information on specific projects, schedules and milestones, and procurement plans. This information has been assembled from Field Task Proposal/Agreements submitted by the national laboratories and research plans submitted by the DOE San Francisco Operations Office.

1.3 Rationale for Federal Program

More than 28 quads of energy are used to heat, cool, light and ventilate buildings, run appliances, and heat water in the U.S. This energy accounts for 36 percent of the total energy consumed and costs users more than 165 billion dollars annually. While the buildings sector has made significant progress over the last decade in energy efficiency, 28 quads and 165 billion dollars represent a significant opportunity to save energy, reduce costs, and minimize peak demand (thereby reducing the need for additional generating capacity).

Solar technologies for water heating, space conditioning, and lighting represent promising energy supply alternatives for the residential and nonresidential buildings sectors. Analyses have indicated that advanced solar technologies, based on the utilization of new materials and components, when integrated with advanced conservation technologies, could provide a substantial portion of building energy requirements. The buildings industry, due to its fragmented nature, lacks the R&D resources to perform the required research without Federal participation. In recognition of this, and the potential benefits of solar technologies for building applications, the Department of Energy has established the Solar Buildings Technology Program.

1.4 Multiyear Perspective

The Solar Buildings Technology Program has sponsored research for more than a decade. An extensive base of fundamental knowledge and understanding of the basic technologies for solar heating and cooling of buildings has resulted. This has been accomplished by supporting research in universities, laboratories, and industry in the areas of advanced materials, systems analysis, proof-of-concept experimentation, and performance measurement and evaluations. These activities have not only established that solar technologies are technically viable options, but have also helped in identifying important research tasks that must be addressed before cost competitiveness can be achieved, and commercial viability established.

The Solar Buildings Technology Program's Multiyear Research Plan (MYRP) outlines program goals, objectives, and strategies, and areas of research opportunity and emphasis for the period 1988-1992. The FY 1988 AOP defines the specific activities to be undertaken in the current fiscal year to meet the MYRP goals and objectives. The FY 1988 program continues the change in program emphasis in the manner that was initiated in FY 1986 -- toward a focussed program centering on the three principal end uses of heating, cooling, and daylighting. Within each of these areas, specific technology options that have the greatest potential to meet system or building level goals and objectives have been selected for further research. In addition, systems integration activities continue to receive support to identify how the individual technologies can most effectively be incorporated in residential and nonresidential buildings. The current program increases cooperative efforts with industry and other Federal agencies to leverage program research and to facilitate technology transfer.

1.4.1 Program Mission, Goals, and Objectives

The mission of the Solar Buildings Technology Program is to support the national energy policy goal of fostering an adequate energy supply at reasonable costs, by providing for the development of solar technology alternatives for the buildings sector. The program goal is to develop a technology base that will allow industry to develop solar energy products and designs for the buildings market which are reliable and economically competitive, and can contribute significantly to national building energy requirements. These goals translate into technology objectives to:

- In the near-term (i.e., within five years) provide industry with the information required to improve system performance and achieve acceptable equipment service life and reliability.

- In the long-term (i.e., beyond five years) develop solar energy technologies that can be practically used to supply up to 80% of building space heating and hot water requirements and 60% of cooling requirements in residential buildings; and up to 60% of nonresidential heating, cooling, and daylighting energy requirements, at costs competitive with conventional technologies.

The Multi-year Research Plan describes the specific technical goals and targets for performance, cost, and reliability for the specific technology options.

1.4.2 Program Strategy

In order to accomplish the goals and objectives, the program, in cooperation with the private sector, undertakes research activities that offer promise of dramatically improving the efficiency, cost, and applicability of solar building technologies in the long-term, while providing technical data from testing and analysis of state-of-the-art materials and systems useful to industry in the near-term.

To provide near-term results useful to industry, the program is working closely with the private sector to identify and provide the most appropriate data generated by the Federal R&D program. Industry may then translate that information to the most suitable products and building applications. The program conducts systems analysis and studies which directly support this effort. These activities include monitoring the performance and reliability of installed systems, developing techniques for designing solar energy systems and integrating them effectively with conventional heating, cooling, and lighting systems. Analytical studies also provide feedback to guide further research and to assist the industry in its efforts to advance state-of-the-art solar technologies.

The focus of the long-term R&D effort is on innovative technologies expected to have the greatest energy contribution potential in the residential and nonresidential building sectors during the 1990's and beyond. This includes R&D on technologies for collection, conversion, storage, and delivery of solar energy and the integration of these technologies with the building envelope, interior materials, and mechanical equipment. A key element of the program's strategy is to target R&D efforts on those technologies that may be applied to the broadest range of building types, end-uses, and climates.

Other important elements of the strategy include:

- Cooperative efforts with the buildings industry in program planning, implementation, and review, to strengthen industry involvement in program activities.

- Continued exploration of mechanisms for private sector involvement in research to increase the effectiveness of program efforts.

- Continued coordination with DOE Buildings Conservation R&D Programs to ensure that advances in conservation with important implications for solar buildings are taken into account.

- Expanded cooperative efforts with other Federal agencies, such as the Department of Defense (DOD), which also have building energy programs and interests in constructing and operating energy efficient buildings.

- Participation in international cooperative research agreements established through the International Energy Agency (IEA) and bilateral agreements with other countries.

1.5 Program Directions for FY 1988

The FY 1988 Solar Buildings Technology Program emphasizes solar technologies capable of being effectively integrated into buildings. In keeping with industry recommendations, the program emphasizes materials research and systems research activities within each of three principal technologies: solar heating, solar cooling, and daylighting. The program also conducts research required to integrate these technologies with conventional building components and systems. Specific areas of emphasis include:

Solar Heating

- Generic heating systems research focusing on solar water heating. The intent is to improve the overall effectiveness of these systems by developing procedures for designing, testing, and evaluating system configurations with the broadest applicability for various building types and climate regions.
- Analysis of annual systems that can lead to improved year round solar utilization and improved cost effectiveness.
- Innovative systems that can increase the reliability and cost effectiveness of current designs.

Solar Cooling and Dehumidification

- Desiccant dehumidification systems and materials that will significantly increase the performance and lower the costs of solar-driven desiccant cooling systems.
- The combined use of distributed desiccants and ventilative cooling, for effective solar driven building dehumidification using passive techniques.

Daylighting

- Optical switching aperture materials for perimeter daylight/heat control, emphasizing electrochromic materials.
- Materials and systems to provide daylight to core areas of nonresidential buildings, emphasizing non-mechanical light collection methods, light transport technologies, and aperture materials that can provide directional light control.
- Atria studies focusing on designs and design methods that can provide daylighting and net thermal energy benefits.

Solar Systems Integration

- Design tools for combined residential solar heating and cooling systems and for integrating solar heating, cooling, and daylighting technologies in small, nonresidential buildings.
- Performance monitoring using short-term measurement techniques.
- Simplified integration methodology using modular functional space approach to establish a framework for conducting whole building systems analyses, and to establish performance criteria.

2. TECHNOLOGY STATUS AND POTENTIAL

2.1 State-of-the-Art

Significant strides have been made in both the advancement of solar technologies for buildings and in the development of the industry infrastructure for solar buildings technologies. Between 1974 and 1986 an estimated 900,000 - 1 million active solar systems (primarily for residential domestic water heating) have been installed, and more than 225,000 homes and 34,000 nonresidential buildings incorporating passive solar energy features have been built.

2.1.1 Solar Heating

Residential solar water heating systems are available at costs that range from \$2,000-\$5,000, and offer potential savings from 40% to 70% in annual hot water heating expenses. Recent trends are toward system simplification--integrated collector storage systems and all water drainback systems. The primary improvements required for these systems are reduced costs and improved reliability. In addition, laboratory and field evaluations indicate that performance could be substantially increased by improved operational strategies. For example, performance gains of up to 15% have been recorded in the laboratory by simply reducing the fluid flow in the collector loop.

Solar space heating systems, of both active and passive design have been deployed in the field with varying degrees of success. Active space heating systems operate in much the same way as solar water heating systems, but require larger collector array areas and thermal storage units and more complex control systems. Active solar heating systems are still relatively high in cost. Residential systems costs are typically between \$8,000 and \$15,000, although smaller systems that do not incorporate storage are available at somewhat lower costs. Typical savings are from 30% to 70% of annual heating expenses. Significant cost reductions, increased reliability, and performance improvements will be required to meet the performance/cost ratios of conventional space heating systems. Advances such as large area collectors, new materials for low cost collectors, storage and distribution systems, and effective systems integration within the building (multifunction applications), will enable such improvements to be realized.

First generation passive solar heating systems have proven to be successful in contributing solar energy for heating single-family homes and small nonresidential buildings. The measured performance of 48 new, single family detached passive homes indicated passive features provided an average of 39% of heating energy requirements. The monitored performance of small nonresidential passive buildings tracked by the DOE program exhibited 46% savings in heating, lighting, and cooling energy use compared to conventional buildings of equal size. The initial cost of these buildings was within 10% of the cost of comparable energy conserving buildings and in many cases no more costly.

Design and analysis tools for passive designs that incorporate storage walls, direct gain systems, and sunspaces, have been developed for single family and small nonresidential applications. However, the applicability of these concepts must also be extended to more complex structures. In addition, improved performance and automatic operation could be achieved with advanced windows that reduce heat losses, and advanced thermal storage and transport systems that provide greater flexibility, control, and capacity for thermal energy storage and distribution. Recent developments, such as low heat loss, low-emissivity (low E) glazings, have already demonstrated the promise of these advances in improving the cost effectiveness of passive solar heating systems and extending their range of applicability.

2.1.2 Solar Cooling

In active solar cooling a number of different concepts involving solar-(thermally) driven absorption, Rankine, desiccant, and hybrid configurations have been studied, with a few experimental units reaching the marketplace. Currently, solar desiccant and solar absorption systems are the active cooling technology options that appear to have the greatest potential. Thermally driven absorption and desiccant cooling systems are presently being marketed, however few of these systems are amenable to solar energy activation without significant modifications. The costs of the most recently marketed solar systems ranged from $4,000-$10,000/ton of cooling (installed). Such systems have demonstrated the capability of meeting 40% or more of a building's cooling requirements. However, a factor of 3 increase in system performance-to-cost ratio is required before these systems can be economically competitive with conventional electrically driven air conditioning systems in most applications. This will require improvements in system performance including reducing the amount of auxilary energy needed and reductions in system costs. Recent advances in solar desiccant dehumidifier technology and high temperature absorption chiller technology, coupled with high efficiency, lower cost collection and storage subsystems, could enable the achievement of the required performance and cost levels.

Passive solar cooling options relying primarily on natural ventilation and evaporation, sky radiation, and dehumidification to provide a cooling effect are used in residential buildings in some portions of the U.S. Ventilation strategies include proper placement of windows and vents to maximize wind capture, designs that induce air circulation using the chimney or stack effect, and designs that use cool night air to precool building storage elements. Vented mass walls, operable clerestory windows, and vented storage elements (e.g., hollow concrete block floors), have been found to be effective for these applications. Evaporative cooling strategies include the use of roof spray systems to reduce roof surface temperatures thereby indirectly reducing building air temperatures, and fan-forced evaporative coolers.

While many of these options have proven successful in reducing conventional air conditioning requirements, they are constrained by climatic considerations, and by the limitations of currently available materials and systems. This is particularly true for hot, humid climates. Passive solar designs incorporating high efficiency direct and indirect evaporative cooling techniques, and desiccant materials can increase the applicability and effectiveness of passive solar cooling.

2.1.3 Daylighting

Daylighting is the use of sunlight to provide a building's lighting requirements. Daylighting technologies are categorized as either perimeter or core systems depending on whether natural illumination is provided to the spaces directly adjacent to the building exterior or to interior spaces, respectively. Since solar radiation is both a source of heat and light, daylighting use has implications for heating and cooling loads as well as electrical lighting requirements. The selective control of the quantity and quality of light transmitted is central to all the daylighting technologies.

Technologies for naturally illuminating perimeter offices and interiors of single story buildings (or the top story of buildings) are currently available, although design information remains limited and adequate design tools are still lacking. Among the more common approaches for perimeter daylighting are light shelves, roof monitors, and sidelighting. Roof aperture systems typified by skylights and roof monitors have proven effective in providing adequate illumination levels and reducing cooling loads imposed by artificial lighting systems (see Figure 1-5). Improved daylighting systems are needed that can overcome the problem of fluctuations in solar availability. New glazing materials with optical switching capabilities, that can dynamically control the transmission of heat and light in response to interior conditions, could significantly increase daylighting contributions to buildings.

With the exception of atria, very few core daylighting systems are in current use. Atria designs have gained in popularity as a result of their amenity value. Little information exists on the energy impacts of current atria designs, or on methods to integrate light collection, transport, and distribution systems with conventional lighting and HVAC systems. New technologies which can collect, transport, and distribute light to the core areas of buildings offer promise of more flexible alternatives for daylighting.

2.1.4 Industry Status

Prior to the expiration of the Federal residential solar energy tax credits in 1985, the solar market was strong and stable with estimated sales of active solar water and space heating systems alone estimated to be between $700 million and $1 billion annually. Between 1984 and 1986 solar collector production dropped from 15.4 million square feet to 4.9 million square feet, and sales fell to an estimated $112 million. Most of this drop was attributable to the decline in residential active solar water heating system sales which fell more than 80% during this period. Solar pool heater sales now predominate, accounting for 72% of total collector production and once again regaining the dominant position they held until 1982. The number of solar collector manufacturers has dropped from more than 200 in 1984 to perhaps 30 in 1987. Overall employment in companies manufacturing, selling, and installing active solar systems has dropped from 30,000 to 3,000. On the other hand, passive solar technologies continue to make progress in the residential building market. For example, sales of low emittance windows, which are frequently used for both new and retrofit construction, continue to increase.

U.S. collector and solar hot water system manufacturers face competition in domestic and international markets from several manufacturers based overseas. Australia and Israel have been successfully marketing thermosiphon systems in the U.S. and worldwide through subsidiaries. A Swedish company has made market gains in the sale of metal absorbers for solar collectors through Canadian and U.S. based subsidiaries. Japan has also begun to establish an export market for its solar heating and cooling products. Evacuated tube collector technology primarily for space heating applications, is exported by European and Japanese firms. Sweden is now leading in the development and application of large scale solar heating systems using seasonal storage and very large collector panels. Since 1982, imports of solar collectors to the U.S. have exceeded exports by 50%. In addition, while in 1984 imports accounted for 4% of the U.S. solar collector market, the steep decline in U.S. production and sales has boosted imports to 10% of total collector sales in 1986. Additionally, the Japanese and Europeans are attempting to increase their share of the world glazing markets in the sale of high performance glazings. These glazings are expected to assume increased significance in future developments of passive solar systems.

2.2 FY 1987 Program Accomplishments

During 1987 significant progress was achieved on several fronts. In the solar heating research area, several design guides were developed that significantly improve capabilities to design high performance, high reliability solar systems. In addition, research on high heat capacity thermal energy storage materials made significant strides toward achieving a commercially viable product. Research in solar cooling identified several low cost polymer materials that could be used as desiccants in a solar desiccant dehumidifier. These materials in conjunction with high efficiency dehumidifier designs, could increase dehumidifier performance by 40% - 70%. Electrochromic devices capable of automatically, and reversibly transmitting or rejecting sunlight as needed, demonstrated stable operation after being subjected to thousands of switching cycles. Use of this daylighting technology could significantly reduce electric lighting and cooling energy requirements. In the systems integration area, a multiyear cooperative effort with the buildings industry culminated in the development of a practical procedure to determine the long-term thermal performance of residential solar buildings and integrated building systems based on short-term tests. The following discussion describes these and other advances in each of the four major program areas.

2.2.1 Solar Heating

- A design manual for commercial size active solar water heating systems was completed, incorporating more than ten years of Federal and private sector experiences. The manual addresses all key requirements for successfully designing large service hot water systems: site and building suitability, most effective design configurations for specific applications, materials and components selection, and system integration and control.

- Research on advanced compound parabolic concentrator (CPC) evacuated tube collectors yielded several new optical designs that promise to increase performance without increasing costs. In addition, system experiments involving an evacuated tube collector-based space heating system identified a control strategy that could substantially increase the daily collection efficiency. This research is part of an ongoing multinational effort to develop a versatile, cost effective collector that can be used for applications ranging from domestic water heating to high temperature cooling or process heating applications (60°C-200°C).

- A series of design information booklets on passive solar residential design and construction were drafted. The booklets incorporate knowledge resulting from the research carried out by the U.S. and other members of the International Energy Agency (IEA).

- Research on high energy storage capacity phase change materials (PCMs) for use in passive solar heating systems resulted in several advances. Most notably, a method of improving the fire resistance of alkyl-hydrocarbon PCMs impregnated in plasterboard was identified. This will help eliminate one of the major concerns regarding the use of this class of PCM. Analytical studies have indicated that the use of these PCMs distributed throughout a room, could improve passive system performance as compared to conventional systems employing sensible storage strategies.

2.2.2 Solar Cooling

- Analyses conducted in 1987 indicated that desiccant dehumidifiers using solar energy to regenerate the desiccant (i.e., to drive off the moisture) could achieve a Coefficient of Performance (COP) of 1.7 or more. This is a substantial increase from current technology which can only achieve COPs of 1.0. This higher performance would enable the use of a smaller collector array to achieve the same level of cooling and result in an overall reduction in system costs.

- Testing of 22 candidate polymer materials revealed several with the necessary water absorbing and regeneration characteristics to serve as high performance desiccants in advanced (high COP) desiccant dehumidifiers.

- In the area of solar absorption cooling, emphasis shifted from research on closed cycle absorption systems to open cycle absorption. Analyses indicate that an open cycle absorption system could provide up to 70% of the cooling requirements of residential buildings in many regions of the U.S. Experiments on a prototype unit were used to validate models of major components; most notably the combined collector/regenerator.

- The Solar Cooling Research Facility continued to expand its capabilities for developing strategies for passive cooling in hot, humid climates. Initial building material property data was collected which will be used in developing more accurate models of moisture absorption and desorption in buildings. In addition, research on diurnal cycle systems using desiccant materials was conducted. Preliminary analyses indicate that 40%-50% of cooling loads could be met by using desiccant materials directly within the buildings structure for dehumidification, in conjunction with ventilative or radiative cooling.

2.2.3 Daylighting

- Electrochromic coatings based on various metal oxides were investigated to determine optical performance, ease of fabrication, and cyclic durability. These coatings can reduce both cooling and lighting requirements by acting as automatic shutters -- darkening during periods of intense sunlight and becoming transparent under reduced sunlight conditions. A small-scale five layer electrochromic device was fabricated using "sputtering" (a film deposition technique), and stable cyclic reversibility was established. In addition, a plasma enhanced chemical vapor deposition (PECVD) process for fabricating multilayer electrochrome devices was demonstrated.

- Research on holographic diffractive structure (HDS) window films capable of directing sunlight at fixed angles up to 20′ to 30′ within a building, also continued in 1987. An experimental HDS was fabricated and demonstrated the feasibility of the concept. The successful development of HDSs could increase the utilization of daylighting for building interiors, and would make daylighting possible for longer periods during the day.

- An analytical model characterizing the performance of light guides was developed. The model will be used in conjuction with experimental research to determine required performance criteria for light guide systems.

- Work on high transmittance/high insulating microporous glazing materials consisting of silica aerogel, focused on methods to improve clarity and the development of techniques to produce larger sample sizes for evaluation by industry. Coloration problems with the glazing were significantly reduced, and the capability to produce larger (10" x 10") samples established. This material has the potential for significantly increasing solar energy contributions in buildings by permitting net heat gains through windows even in cold, cloudy climates.

- A procedure for predicting the long-term performance of daylighting systems based on data from short-term tests was developed. A full scale test of the procedure was performed on an English office building, as part of a bilateral agreement with the United Kingdom. The "Daylighting Performance Evaluation Method" is a low cost approach for obtaining performance data with potential applications for a wide variety of daylighting systems.

2.2.4 Systems Integration

- In 1987 prototype passive solar design guidelines for home builders were introduced. The guidelines packages are composed of written guidelines, a simplified calculation procedure and worksheet, and an example building for which the calculation procedure and worksheet, and an example building for which the calculation procedure is applied. Development of the guidelines package resulted from callaboration by industry and researchers and incorporates results of research carried out during the past ten years. It will be possible to generate guideline packages for 2400 locales.

- In another cooperative effort with industry, a protocol for determining the long term thermal performance of a building from short-term test data was developed. The methodology involves a relatively short (3-5 day) test period and measurements of only a few building parameters to determine overall energy consumption. It is anticipated that the method will be used by the buildings industry for determining the energy performance of buildings, and as a diagnostic tool.

- Research on room to room convective heat transfer indicated that the performance of passive solar buildings could be improved by 30%-50% by the use of heat absorbing windows and thermally coupled storage. The higher temperature of the heat absorbing windows increase the temperature difference between the thin layer of air adjacent to the window and the air in the rest of the room. Due to the higher temperature of this heated air relative to the air in a conventional passively heated room, more effective heat transfer occurs.

2.3 Research Needs

2.3.1 Technology Potential

The relatively low use of the available solar resource points to significant opportunities for increasing solar contributions for meeting building energy requirements. For example, advanced glazing materials with the equivalent thermal resistance of a conventional R-11 wall will permit more extensive use of glazing than is currently possible, dramatically increasing the opportunities for providing solar heat in northern climates. New desiccant materials and dehumidifier designs will double the performance of current units and could enable solar cooling to become a practical reality. The development of advanced daylighting techniques that can automatically modulate the intensity, direction, and distribution of sunlight in response to comfort requirements will significantly decrease electrical lighting requirements without increasing air conditioning needs. The challenge is to identify and develop those materials and systems that can efficiently convert a greater portion of this resource into useful energy in a cost effective and reliable manner. A major focus of the national program is upon research that will lead to the next generation technology that would reduce system energy delivery costs by factors of 2 to 4, and increase solar contributions up to 80% of building energy requirements.

2.3.2 Solar Heating Research Needs

Significant reductions in system costs and improvements in reliability are required to make active solar space heating systems competitive with conventional technologies. Improved system integration in larger installations and more reliable control systems are needed. Reductions in the cost of delivered energy from collectors, either through cost reductions or efficiency improvements, are needed.

The practicality and effectiveness of applying passive heating strategies to multifamily and larger, nonresidential buildings has not yet been established. Improvements are needed in single-family residential applications of passive systems such as a Trombe Wall, direct gain or sunspaces, which sometimes have adverse effects on the home's energy performance and comfort during the summer and swing seasons. Current systems only capture and convert a relatively small percentage of the solar radiation incident on buildings into useful heat. Methods to increase the collection of solar energy and to store it efficiently and inexpensively are also required. Research is also needed to develop advanced technologies which can meet the heating and cooling requirements of new and existing multifamily dwellings and nonresidential buildings.

2.3.2 Solar Cooling Research Needs

Improvements in the performance of advanced absorption chillers and desiccant dehumidifiers, and reductions in the cost of high performance collectors are needed to achieve commercially viable solar cooling based on active solar technologies. Reductions in auxiliary energy required to power pumps and fans are needed as well.

Individual passive cooling techniques such as natural ventilation, hybrid ventilation, and hybrid evaporation are climate sensitive. Furthermore, there is a time-of-day mismatch between cooling energy requirements and passive cooling resources. Consequently, meeting building cooling requirements with passive techniques remains a major challenge. This is particularly significant for multifamily and nonresidential buildings which have greater cooling requirements. Thus, there is a pressing need to develop a range of new engineering concepts which optimize the combination of the active and passive cooling technologies with the conventional back-up systems for both residential and nonresidential buildings. In addition, techniques for building dehumidification are needed; particularly for hot, humid regions.

2.3.4 Daylighting Research Needs

The development of daylighting systems that can adequately meet interior lighting requirements without excessive heat gains or losses remains an important challenge. While progress has been made in developing roof aperture systems that can be adapted to specific types of nonresidential buildings, research is required to develop more generally applicable techniques. Advanced non-mechanical daylight collection systems, daylight transport technologies, and holographic films hold the promise for significantly increasing design options using natural illumination for building cores. Improved methods for perimeter daylighting/thermal control are also needed to increase daylighting contributions.

2.3.5 Solar Systems Integration Research Needs

Optimizing the mix of solar technologies and conventional energy-conserving building systems is a continuing high priority need. Understanding complex building system interactions and means to effectively combine and control various materials, components, and systems remains a major challenge. Integration of solar collection equipment to service the combined cooling, heating and hot water needs of a building in an optimal manner is a direct challenge which has not yet been addressed; especially when this equipment must be integrated with a conventional back-up HVAC system. Specific analytical and experimental investigations ranging from basic heat transfer studies to system/component control tests need to be undertaken. To assist designers, home builders, and building owners, design and analytical tools are also required.

3. PROGRAM DESCRIPTION

3.1 Program Structure

The Solar Buildings Technology Program is organized by the principal technology applications of Solar Heating, Solar Cooling and Dehumidification, Daylighting, and by Solar Systems Integration. Exhibit 3-1 illustrates this structure, along with some of the major areas of research activity. Specific FY 1988 activities under each of these program elements is provided in the following sections.

3.2 Solar Heating

The principal focus of solar heating research activities in FY 1988 will be on generic heating systems and supporting systems effectiveness research. These activities are aimed at addressing the near-term objectives of providing industry with the information required for developing improved state-of-the-art active systems. In addition, research will be conducted on advanced systems.

Collector Materials and Concepts - In recent years, a significant effort was devoted to exploring the use of low-cost polymers in flat plate collector configurations. Various prototypes were developed, and it was concluded that low cost thin film polymer collectors were technically feasible, but still had potential problems with long-term durability. Current efforts have shifted to the development of integrated compound parabolic concentrator (ICPC) evacuated tube collectors for both solar heating and cooling applications.

The objective is to develop a collector that can prove economically competitive for solar water and space heating applications requiring temperatures in the 120° F - 180° F range, as well as for higher temperature cooling (>250° F) applications. Activities in this area will be limited to analyses of advanced designs incorporating features from the integrated stationary evacuated collector previously developed under program sponsorship, and advanced evacuated tube collectors. This includes evaluation of improved absorber and reflector coatings, determination of the performance potential of glass absorbers and insert heat pipes, and the development of ICPC performance models.

Thermal Storage and Transport - Thermal storage research focuses on the use of phase change materials in combination with conventional building materials for solar applications. Recent efforts have identified several classes of materials -- fatty acids (crystalline alkyl hydrocarbons), polyalcohols -- that undergo solid-solid phase transformations, upon heat addition or removal. Composite materials consisting of these PCMs and gypsum wallboard have been developed and appear promising for widespread applications. In FY 1988, the focus will be on testing the heat storage capacity, reliability, durability, and safety (primarily fire safety) of several scaled-up composite PCM wallboard and alkyl hydrocarbons PCM masonry units, and improving their fire retardant capabilities for all applications. In addition, work on optimizing the properties of neopentyl glycol solid state PCMs for

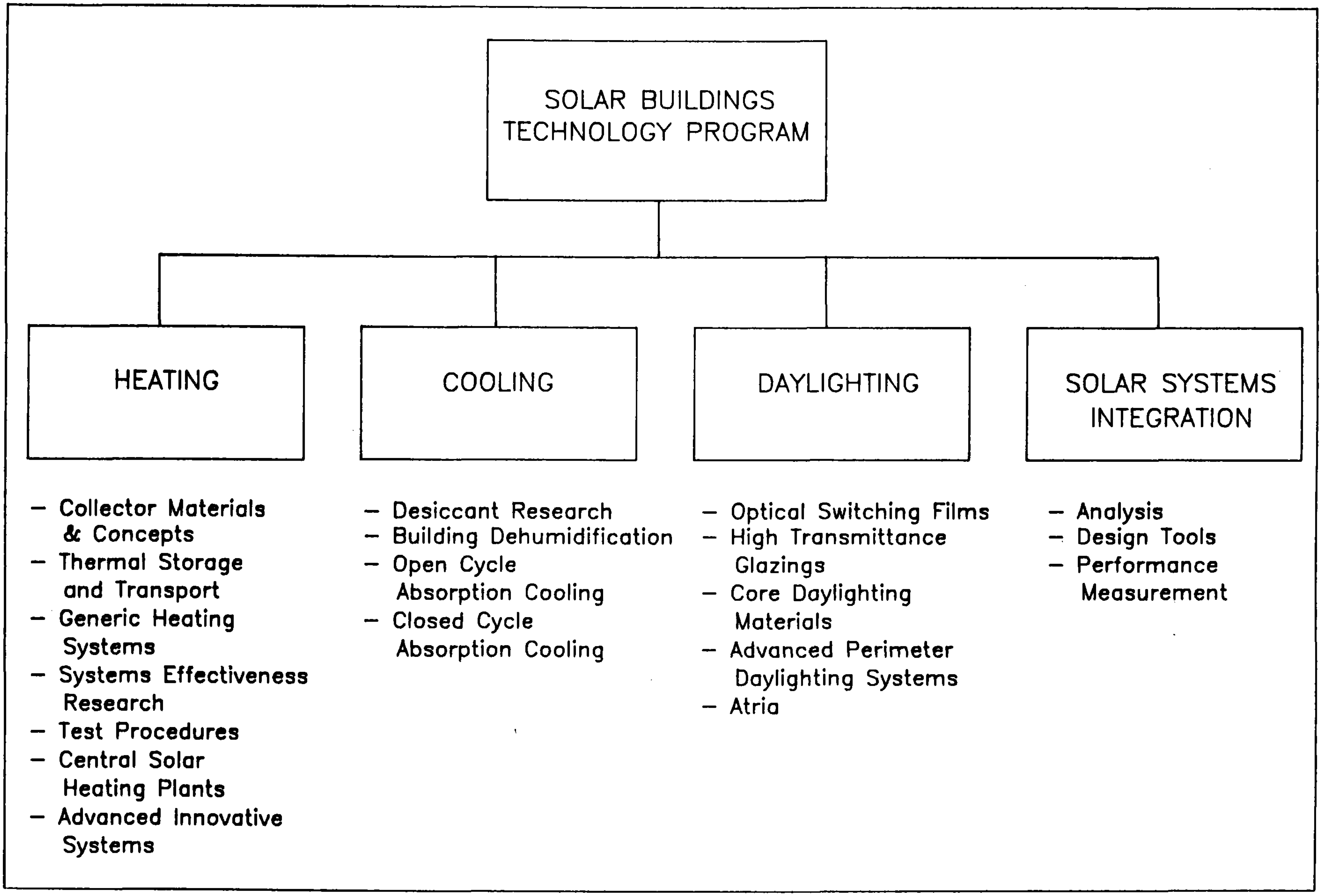


Exhibit 3–1
SOLAR BUILDINGS TECHNOLOGY PROGRAM
FY 1988 PROGRAM STRUCTURE

building applications will be performed. Research in this area is coordinated with DOE's Thermal Storage Program.

Generic Heating Systems - Activities in this area will focus on generic solar DHW systems for FY 1988, and will attempt to determine the most suitable configurations for widespread applications. Up to four system types will be analyzed and candidate buildings/configurations developed for testing. Identification of the test sites will be a joint activity involving the Solar Energy Industries Association and the Department of Defense. This effort will also be supported by the development of improved analytical models of solar systems that will be incorporated in FCHART 4.3 and TRNSYS. Specifically, models of low flow systems and improved heat exchanger/storage tank subsystems will be developed.

Systems Effectiveness Research - The systems effectiveness research (SER) efforts will involve activities supporting the development of generic heating systems as well as a continuation of ongoing efforts in laboratory testing of subsystems, components, and materials. Joint efforts will be conducted with industry to obtain thermal performance, reliability, and maintainability data on state-of-the-art installations and to identify the best applications for the generic systems. Results of previous SER activities will be provided to industry tailored for their needs.

Test Procedures - Short term, nonintrusive test procedures for predicting the long-term performance of solar DHW systems will continue to be a focus of efforts in FY 1988. Such methods have already been developed for ICS systems and will be extended to the generic systems configurations identified in concert with the solar industry. The methods will be developed jointly with the Solar Rating and Certification Corporation (SRCC) and will provide valuable information on predicting long-term thermal performance. In addition, they will aid in diagnosing problems during acceptance testing. The use of the methodology in conjunction with a microcomputer based expert system will also be explored.

Central Solar Heating Plants - The program will continue to participate in research on central solar heating plants with seasonal storage (CSHPSS) as part of its commitment under IEA Task VII. This will involve performance monitoring and evaluation of CSHPSS plants, (potential participation) in a U.S. CSHPSS project in concert with the efforts in the DOE Buildings and Community Systems Programs, and coordination of activities to maximize U.S. benefits from the U.S./Denmark project.

Advanced Innovative Systems - Research on the scaled-up self-pumping building collector systems will be concluded with completion of seasonal tests. Preliminary tests identified problems with the basic system that led to significant performance penalties and inferior overall performance compared to a conventional active solar system. The (optimal) system configuration will be evaluated in terms of thermal performance and reliability to determine its potential as an alternative to conventional active systems that require external sources of energy to power pumps and fans. In addition, research will be initiated on innovative concepts that have been identified by recent studies such as the SERI industry survey (1987) and the Comparative Systems Analysis (1986).

3.3 Solar Cooling

Solar cooling and dehumidification research activities will focus on solid desiccant cooling and building dehumidification using active and passive solar strategies. In addition, analytical and experimental work on open cycle absorption cooling systems will be undertaken.

Desiccant Research - Research on solar desiccant systems will focus on solid desiccant materials and improved heat and mass transfer dehumidifier designs to enable COPs of 1.5 for temperature ranges of 130-170°F to be achieved by 1990. Materials research will continue to emphasize polymers and composites for desiccant applications, several of which have been identified as having potentially superior properties to conventional desiccant materials. The objective is to identify materials with the optimal characteristics, or with the ability to be modified to achieve high performance (e.g., increased sorption capacity) in the intended applications. A number of others polymers that were initially identified will be screened based on tests delineating key characteristics - sorption capacity, sorption isotherm shape, and cyclic durability.

Various dehumidifier geometries will be evaluated and tested in combination with the most promising desiccant materials to determine which material/geometry combination can achieve the COP goal. Recent efforts have indicated parallel passage designs offer the greatest potential for improving dehumidifier performance, and will continue to be the focus of research in FY 1988. Joint efforts with desiccant dehumidifier manufacturers to test the material/geometry configurations will be continued. In conjunction with these efforts, analytical models will be developed to aid in understanding of the performance of the dehumidifier, and to establish requirements at the systems and subsystems level. In addition, investigations of other configurations such as hybrid desiccant/vapor compression will be undertaken to determine their potential.

Studies of possible degradation due to desiccant contamination will also be undertaken. Initial analyses have indicated that desiccant contamination could reduce the thermal COP of a desiccant dehumidifier by as much as 35%. A contamination test facility will be fabricated and initially used to evaluate the impacts of tobacco smoke on commercial desiccants such as silica gel. The extent of contaminant effects on performance will be determined and degradation reducing options developed.

Building Dehumidification - For the past two years the program has conducted extensive efforts to gain a better understanding of the cooling requirements in hot, humid climates. Building dehumidification has been identified as the area requiring the greatest attention, and one which could be addressed by new passive systems. Moisture research analysis will be conducted to gain an insight into the moisture capacitance of common building materials as a basis for these efforts. Algorithms describing moisture transport in residential buildings will be developed using the data, along with a materials moisture properties handbook. Strategies for moisture removal using desiccant materials within the building structure in conjunction with ventilation or other means to transfer the moisture from the desiccant outside the building will be explored. An experimental residential test configuration will be developed to determine the effectiveness of the most promising strategies.

Open Cycle Absorption Cooling - Research on open cycle absorption cooling systems as well as liquid desiccant systems will involve evaluations of strategies to mitigate the effects of contamination on desiccant carryover, and methods to improve heat and mass transfer. Different collector/regenerator designs will be evaluated for increasing heat and mass transfer rates. This will involve experimental as well as analytical studies using the residential size open cycle system prototypes developed under previous program efforts. Performance enhancing fluid additives and alternative low-cost absorbent fluids will also be investigated. A new falling film absorber will also be designed for test in this system.

Closed Cycle Absorption Cooling - Recent work in this area has focused on the development and application of computer models to determine the performance of advanced, high COP cycles. These cycles are currently under development by DOE and industry for gas and waste heat thermal inputs. This work will be continued as part of a joint U.S.-Israel bilateral agreement to improve capabilities to evaluate complex absorption chillers and heat pumps. The research will involve a comparison of the capabilities of a simplified model vs. a more rigorous and detailed simulation tool. The models will be used to determine the suitability and performance potential of these cycles for solar applications; particularly in systems using ICPC collectors.

3.4 Daylighting

Daylighting research will focus on optical switching aperture materials for automated daylighting control; advanced concepts for core daylighting including light guides and holographic films that can provide directional control; and improved designs and performance prediction tools for atria systems. Research on optical switching films will receive the highest priority.

Optical Switching Films - The major objective of research on optical switching films is to increase control of solar heat and light transmission to enable apertures to provide net benefits for daylighting on a year round basis, minimize cooling loads in the summer, and increase solar heat gains in the winter. Over the past few years the emphasis has been on chromogenic materials (electrochromic, thermochromic, and photochromic), to control spectral transmittance (e.g., thermal energy and visible light). Small scale electrochromic film assembles have demonstrated their ability to switch reversibly from the clear to the opaque state in response to an applied voltage. The focus of the FY 1988 effort will be on a scale up to larger size prototype units, and on the optimization of the individual films that make up the multilayer assembly. The electrochromic materials that will be scaled up include tungsten oxide and molybdenum oxide based films. In addition, investigations of nickel oxide based devices will continue. Processes to be explored for practical scale-up include various vapor deposition techniques, and a potentially lower cost sandwich technique similar to that used in the construction of safety glass. Other efforts will focus on developing methods to predict the durability of electrochromic devices based on short-term laboratory tests.

System studies will also be undertaken to establish the potential benefit of thermochromic and photochromic optical switching materials. For select building types and climates these materials may be attractive. They are potentially less expensive and simpler (e.g., single layer vs. multilayer for electrochromics) and may be more easily adapted into the market place. Thermochromic and photochromic materials change transmissivity in response to changes in temperature and solar intensity, respectively. Research on potential photochromic materials focuses on the development of a plastic consisting of a polymer containing a photochromic dye and various light stabilizers. The degree of light transmitted is governed by the amount of ultraviolet light absorbed by the photochromic material.

High Transmittance Glazings - Research on high transmittance, high thermal resistant glazings made of silica aerogels will be concluded in FY 1988 with the fabrication of 10" x 10" samples for industry evaluation. This technology transfer effort builds upon the successful development of an aerogel material that closely approximates view window optical requirements.

Core Daylighting Materials - FY 1988 research will focus on non-mechanical daylighting collection technology, a collector/light guide subsystem, and holographic devices. Research on the collector/light guide subsystem will involve design optimization and simulations to establish performance requirements and benefits. Research begun in FY 1987 on a non-mechanical daylight collector will continue. The objective is to develop a high transmittance lens system that can collect sun over a wide range of directions and then emit it over a smaller angular range. Prototype 6" x 6" lenses will be fabricated and tested in the laboratory.

Holographic devices have also been under investigation for several years as a means of directing light at a fixed angle over extended distances regardless of the position of the sun. Experimental holographic diffractive structures (HDS) fabricated using an expensive silver halide emulsion on glass or plastic substrates have demonstrated the technical feasibility of the concept. The current effort is aimed at developing a full size prototype using a low cost process. This HDS will accept solar altitude variations of up to 45°F (the difference in summer and winter noon angle) while maintaining the desired direction of the transmitted light.

Advanced Perimeter Daylighting Subsystems - A review of international literature will be undertaken in collaboration with the United Kingdom and an U.S. and U.K. glazings manufacturer under an existing bilateral agreement. The review will lead to the identification of potential glazing technology options that might be developed for use in the next century.

Atria - Atria have become an increasingly used daylighting technology. They improve interior aesthetics and marketing of the building. The use of atria has implications for building heating and cooling requirements as well as lighting requirements. The objective of the current effort is to improve the overall effectiveness of atria in terms of increasing daylighting contributions, and reducing heating and cooling requirements. This will involve evaluations of various design strategies, and the analysis of performance data from actual installations. Atria daylighting research is an integral part of the effort in systems integration to develop performance evaluation methods and to improve simulation capability for buildings having atria. Atria research in an integral part of collaborative research being undertaken under the U.S./U.K. bilateral agreement and Task XI of the EIA Solar Heating and Cooling Agreement.

In another task, a preliminary assessment of the energy and optical impact of existing glazings and smart (e.g., electrochromic) glazings in atria will be undertaken. Scale models of atria glazings and designs will be developed for this effort.

3.5 Solar Systems Integration

The principal focus of solar systems integration research activities will be on the completion of design guidelines for residential buildings, the adaptation of an analysis procedure using the concept of building functional modules, and short term test procedures for determining whole building performance. In addition, research on IEA tasks relative to passive solar residential and nonresidential buildings will be continued.

Analysis - A simplified methodology for evaluating the performance of nonresidential buildings will be undertaken in concert with the architectural community. This will involve the development and application of a modular functional space approach that treats a building as a collection of basic modules or functional spaces (e.g., offices, kitchens, etc.). The initial effort will determine the feasibility of the approach based on comparisons of building energy use for typical buildings to building energy use for buildings constructed from such modules. Eventually, the method will be used to help establish materials and subsystem performance criteria based on matching the energy requirements of the functional spaces to solar supply characteristics, and as an aid in the design process.

In another effort, research on a novel method to enhance room to room convective heat transfer will be concluded. Full size prototype tests of a system consisting of an energy absorbing window and distributed thermal energy storage will be conducted to determine heat transfer effectiveness, and overall performance. The tests will examine the impacts of low emissivity coatings, room reflectivity, and thermal storage location on performance. The work will be done in collaboration with glass and window manufacturers, and builders.

Research on the energy impacts of passive cooling strategies coupled with conventional cooling or cool storage will be concluded. Preliminary analyses have indicated that with an appropriate control strategy, such an approach could result in reductions in peak cooling demands and overall cooling energy requirements. The results of this research will be documented and distributed to buildings and utility groups.

Design tools - Design guides for passive solar heating and cooling for residential buildings will be completed based on the results of laboratory tests and field monitoring programs. Builder guidelines based on the successful format developed previously will be upgraded to accommodate the requirements of the building community. The software required to generate site-specific builder guidelines will be completed and made available to industry.

In a related effort, a pilot microcomputer based expert system will be developed based on the builder guidelines. The expert system will automate many of the more laborious and time consuming input steps required in the guidelines, provide a rapid determination of energy use effects and tradeoffs, and extend the guidelines capabilities. The tool will enable the determination of the effectiveness of passive heating and cooling options, as well as energy conservation features. Supplement 2 of the ASHRAE manual will focus on cooling calculation procedures.

The development of a procedure for verifying the accuracy and range of applicability of design tools will be continued in FY 1988. The technical basis for the procedure has been developed as part of activities under IEA Task VIII. The FY 1988 effort will involve coordination with a specially formed ASHRAE Standards Subcommittee to develop a test procedure for building energy design and analysis tools suitable for domestic use. Field tests of the method will also be undertaken

Performance Measurement - The focus of efforts in this area will be on the validation of short term monitoring methods that can be used to predict long-term energy performance of residential buildings initially, and later on their extension to nonresidential buildings. Field tests of the joint DOE-NAHB method will be conducted on detached single family homes and on small nonresidential buildings. The methodology will be developed in a software package for use on a microcomputer.

3.6 Planning and Management

Planning and management activities include the development of annual and multiyear program plans, improvements to the research planning process, and technology transfer. A general description of how the Solar Buildings Technology Program is managed and implemented is provided in Section 4. The information below describes specific management activities occurring in the current fiscal year:

- A Multiyear Research Plan (MYRP) for the period FY 1988-1992 will be finalized. In addition, individual research plans for Solar Heating, Solar Cooling, Daylighting, and Solar Systems Integration areas will be prepared that outline specific technology objectives, research paths, and schedules.

- A two-year plan covering FY 1989 - FY 1990 will be developed in FY 1988. The plan will provide brief descriptions of planned activities during the subject time period, budgets, management, and schedule information.
- Collaborative efforts with industry, building on prior efforts and new strategies formulated in FY 1986 will continue.
- Continued participation in research outlined in IEA and bilateral agreements.

4. PROGRAM IMPLEMENTATION AND MANAGEMENT

4.1 Management Responsibilities

The Solar Buildings Technology Division has overall responsibility for the conduct of the Solar Buildings Technology Program including implementing DOE policy at the program level, preparing guidance for planning and assessment, resource allocation, and approval of all major plans, solicitations, and reports. Supporting the DOE Headquarters Division are the San Francisco Operations Office (SAN), the Solar Energy Research Institute (SERI), and Lawrence Berkeley Laboratory (LBL). The San Francisco Operations Office manages contracts with industry and universities, dispenses funds to laboratories, universities, and contractors in accordance with approved plans, and conducts program evaluations and assessments.

SERI has two major roles in the Solar Buildings Technology Program: (1) to serve as the major research center for program activities, and (2) to execute a planning and coordination function through an independent Technology Program Integration (TPI) Office. The SERI/TPI Office has responsibilities for planning, including the development of the multiyear program plan (MYPP), coordinating program planning activities, and organizing meetings with industry to exchange information. The Lawrence Berkeley Laboratory and SERI have primary responsibilities for performing designated technical tasks in coordination with the SERI/TPI. Exhibit 4-1 illustrates the field management structure.

In addition to the major national laboratory research centers, both industry and universities conduct significant elements of the research program. The Florida Solar Energy Center (FSEC), conducts research activities in solar cooling and dehumidification. Colorado State University (CSU) serves as an experimental test center for evaluating the performance of various materials and components such as evacuated tube collectors, and solar absorption and desiccant dehumidifiers in a systems context. Arizona State University (ASU) has a major role in exploring open cycle absorption technologies. The University of Wisconsin provides support in the development of thermal systems analysis tools. Other universities and companies are engaged in research on optical switching films, phase change material storage, and advanced solar heating and cooling concepts.

Management control is maintained through a schedule of periodic reports and reviews to ensure that the program is proceeding as described in approved Laboratory Field Task Proposal/Agreements (FTP/A), the SAN Annual Operating Plan (AOP), and the multiyear program plan. These include:

- o Monthly technical and financial reports prepared by the various field organizations indicating progress relative to the FTP/A's, the SAN/AOP, and the MYPP.
- o Deliverables as identified and scheduled in the FTP/A and the SAN/AOP.

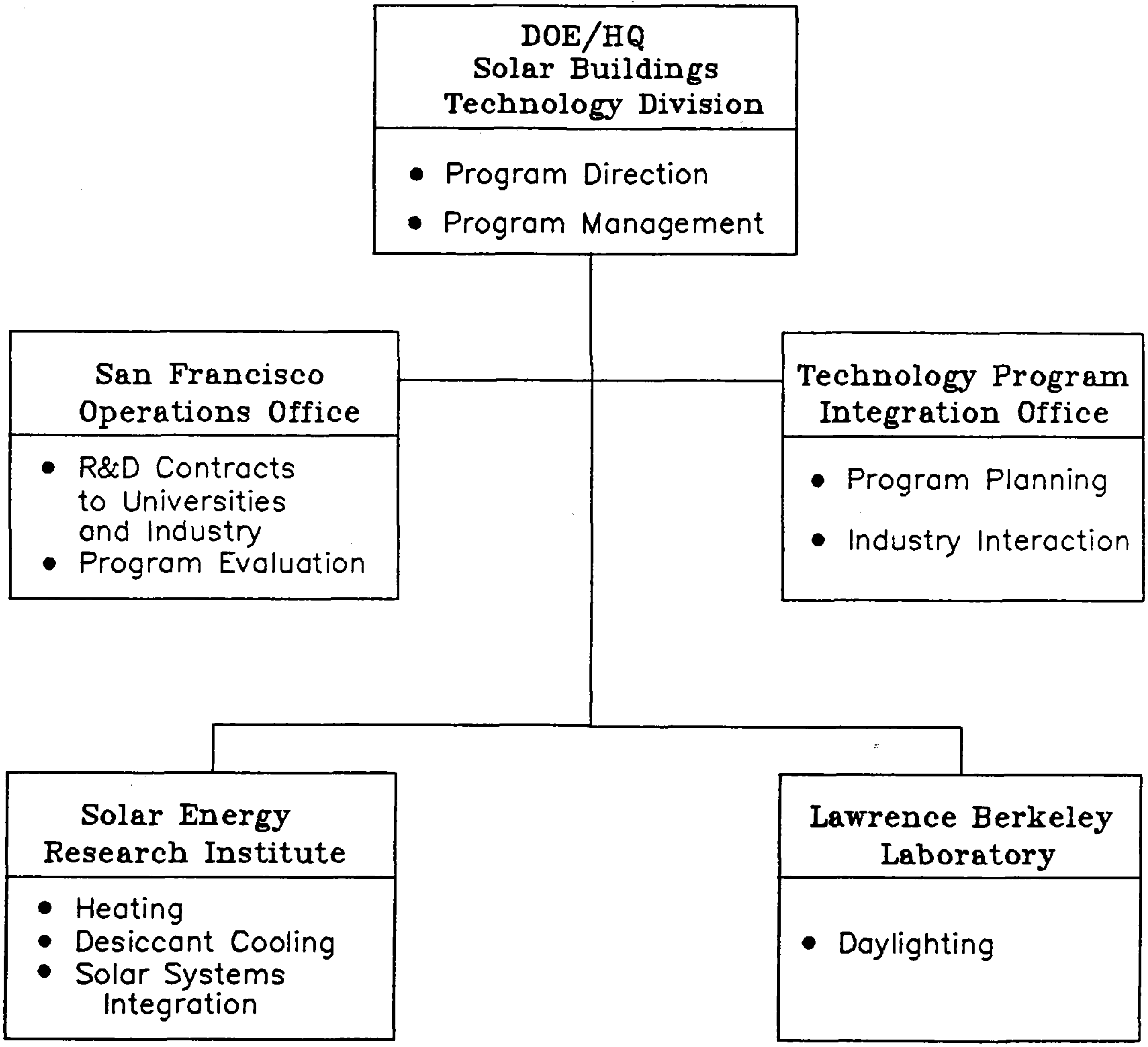


Exhibit 4-1. SOLAR BUILDINGS FIELD MANAGEMENT STRUCTURE

4.2 Program Planning

The program described in this AOP is the result of planning efforts involving DOE staff, the SERI/TPI, national laboratories, industry, and universities. Congressional guidance, Administration policy, and technical inputs based on a review of industry needs and research opportunities served as guides in this effort. Criteria employed to determine the scope of program activities include the ability of each activity 1) to improve system cost effectiveness, 2) to advance solar related technology, 3) to contribute to energy supplies on a national basis, and 4) to contribute to the near-term and long-term requirements of industry. Specific tasks and deliverables were constructed around these activities through the Field Task Proposal/Agreement and the SAN/ AOP development process.

In keeping with the strategy of fostering closer ties with industry, the program has developed a formal process to involve industry early in the planning effort. The SERI/TPI has been organizing meetings and topical reviews with representatives of industry to determine private sector needs and priorities. Industry representatives consulted in this process include glass and window manufacturers, HVAC equipment manufacturers and designers, building material manufacturers, homebuilders, commercial building designers and developers, and solar collector manufacturers. Among the professional and trade organizations that have cooperated in this effort are the National Fenestration Council (NFC), American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), Passive Solar Industries Council (PSIC), National Association of Homebuilders (NAHB), American Institute of Architects (AIA), and the Solar Energy Industries Association (SEIA).

4.3 Program Evaluation

Program evaluation is conducted at three different levels. The first level is an administrative evaluation intended to ensure that the program is on-track in terms of meeting milestones, and to identify and resolve management, technical, or policy problems as they arise in the conduct of work. This is primarily the responsibility of DOE/HQ.

The second level of evaluation involves an assessment of project accomplishments relative to specific materials, components, and system level goals as well as the quality of research. All projects associated with a specific research path within the areas of Solar Heating, Solar Cooling, Daylighting, and Solar Systems Integration are subjected to this evaluation. The technical goals (e.g., cost and performance) are subjected to periodic review, and refinements are made as necessary. Projects that appear unlikely to contribute to significant technology improvements can be redirected or phased out. SAN plays the major role in conducting this evaluation, supported by the SERI/TPI. The review of research quality involves peer reviewers from universities and industry.

The third level of evaluation is designed to ensure that the program is meeting industry needs. Reviews conducted with industry representatives and university researchers serve as a mechanism for exchanging information on

EXIBIT 4-2
SOLAR BUILDINGS TECHNOLOGY PROGRAM
FY 1988 VS. FY 1987 FUNDING COMPARISON
(THOUSANDS OF DOLLARS)

	FY 1987	FY 1988
Solar Heating	1236	1093
Solar Cooling	1185	1050
Daylighting	1148	1272
Solar Systems Integration	1181	1181
Planning and Management	1178	654
Capital Equipment	0	150
TOTAL	5928	5400

EXHIBIT 4-3

SOLAR BUILDINGS TECHNOLOGY DIVISION

Fiscal Year 1988 Funding Distribution -- $5.4 Million Budget

(Thousands of Dollars)

B & R CODE STRUCTURE	LBL	SERI		SAN	HQ	TOTAL
		In House	Subcon't			
SOLAR HEATING (SUBTOTAL)	0	660	100	333	0	1093
Collector Materials & Concepts				63		63
Thermal Storage & Transport Materials						0
Heating Subsystems Research						0
- Systems Analysis		320		160		480
- Systems Effectiveness		220	100	40		360
- Test Procedures		120		70		190
COOLING & DEHUMIDIFICATION (SUBTOTAL)	90	300	0	660	0	1050
Desiccant Materials & Concepts		100		50		150
Chiller Materials & Concepts						0
Cooling & Dehumidification Subsystems Research	90	100				250
- Open Cycle Cooling				110		110
- Building Dehumidification				500		500
- Systems Analysis		100				0
DAYLIGHTING (SUBTOTAL)	610	100	0	562	0	1272
Aperture Materials	120	100		452		672
Daylighting Concepts	135			110		245
Daylighting Subsystems Research	355					355
SYSTEMS INTEGRATION (SUBTOTAL)	95	491	80	515	0	1181
Analysis & Design Tools						105
- Analysis	105	191		265		456
- Design Tools		100	80	250		430
Performance Measurement		200				200
PLANNING & MANAGEMENT (SUBTOTAL)	0	160	0	220	274	654
Technical Program Integration		160		35		195
San Support Contractor				185		185
DOE/HQ					680	680
SUBTOTAL (W/O CAPITAL EQUIPMENT)	795	1711	180	2290	274	5250
CAPITAL EQUIPMENT	22	18		110	0	150
TOTAL SB FY88 W/ CAPITAL EQUIPMENT	817	1729 1909	180	2400	274	5400
TOTAL SB FY87 W/ CAPITAL EQUIPMENT LANL = 335	900	1910		1940	953	5928

industry viewpoints and on new private sector developments. Midyear, annual, and topical review meetings serve as forums for these reviews. The SERI/TPI has primary responsibility for organizing these reviews.

4.4 Technology Transfer

The transfer of research results to potential users is accomplished by three primary mechanisms: (1) industry participation in program planning, (2) direct research involvement, and (3) sharing of research results through publications, industry-sponsored workshops, meetings, and conferences. Direct research involvement gives individual contractors the "hands-on" understanding of the research and its implications. Cost-sharing is generally encouraged or required. In addition, DOE laboratories are encouraged to explore their research concepts with industry. The Southeast Solar Cooling Research Facility at Florida Solar Energy Center, which receives funding from the Gas Research Institute, Florida Power and Light, and the State of Florida is representative of these kinds of cooperative initiatives.

Publication of articles in professional journals and trade magazines is widely used by the program for disseminating research results. The program requires the DOE laboratories to identify planned publications, as well as reviewers and distribution lists, as part of each research activity. This information is reviewed by DOE Headquarters for adequacy. Major reports are made available through the DOE Technical Information Center and through the National Technical Information Service. The program continues to work closely with industry, the SERI Solar Technology Information Program Office, and professional and trade organizations in determining the best formats for this information.

Industry-sponsored workshops, conferences, and meetings are a commonly used method for reviewing progress, redirecting and planning R&D, and sharing research results. The program provides support to contractors and laboratory personnel for presenting their findings at these meetings. In addition, the program sponsors topical review meetings addressing specific technology issues. These generally involve DOE/HQ and field staff, DOE laboratory, university and industry researchers, representatives of trade and professional organizations, and individual companies.

4.5 Program Funding

A comparison of the program's budget for FY 1987 and FY 1988 is shown in Exhibit 4-2. The allocation of funds to SERI, the San Francisco Operations Office, and the national laboratories for FY 1988 research, development, and program management activities is shown in Exhibit 4-3. Milestone and schedule information for these projects is presented in Appendix A.

SOLAR HEAT TECHNOLOGIES

SOLAR BUILDINGS TECHNOLOGY PROGRAM

DIVISION DIRECTOR : DAVID PELLISH

ACTIVITY	ORG	FY - 88												FY - 89						
		1st QTR			2nd QTR			3rd QTR			4th QTR			1st QTR			2nd QTR			
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	2 Half
I. SOLAR HEATING																				
1. Solar Heating Research and Development	SERI													105 101 △△		103 102 △△				
2. Exposure Testing	LANL													104* △						
3. Advanced Evacuated Tubular Concentrator Research	SAN								106* △		107 △		108 △							
4. Multilateral Evacuated Tube Collector Research	SAN										109 △		111 110 △△							
5. Advanced Phase Change Materials and Systems for Solar Passive Heating and Cooling of Residential Buildings	SAN											112* △								
6. Thermal Energy Storage in Plastic Crystals as Incorporated in Building Materials	SAN																			
7. Solar Thermal Energy Conversion Technology Status and Assessment Program	SAN								130* 126* △△		125* 128* △△		129* △			127* △				
8. SFBP - IO&M Manual	SAN															137 △				138* △
9. SFBP - General	SAN										152 △					153*, 154 157* △△△			161 △	156 155 △△
10. IEA Task VII: Technical Support Services	SAN												160 △							

SYMBOLS: △ PLANNED ▲ COMPLETED ⩚ DELETED * KEY MILESTONE

SOLAR HEAT TECHNOLOGIES

SOLAR BUILDINGS TECHNOLOGY PROGRAM

DIVISION DIRECTOR : DAVID PELLISH

ACTIVITY	ORG	FY - 88												FY - 89						
		1st QTR			2nd QTR			3rd QTR			4th QTR			1st QTR			2nd QTR			
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	2 Half
II. SOLAR COOLING																				
1. Desiccant Research and Development	SERI											201 △	202 △	203 △	204 △	206* 205 △△				
2. Cooling Research: Advanced Technology Approaches	LBL						207 △						208 △							
3. Simulation and Analysis of High Efficiency Absorption Systems for Solar Cooling	SAN							248 △			249 △		214 △							
4. Southeast Solar Cooling Research Facility	SAN									260 △	216 △						261 △			
5. Open-Cycle Absorption Solar Cooling	SAN								233 △	232, 229 228 △△△		234 △			211* △					
6. House I	SAN						265 △						238* △							
7. House II	SAN								240 △				241* △							
8. House III	SAN								244 △		270 △	271* △	236 245 △△							
9. Data Collection and Model Development of Liquid Desiccant Cooling Systems	SAN																			
10. Research on Active Solar Processes	SAN									253* △										
11. Materials with Enhanced Transport Properties for High Performance Desiccant Systems	SAN											257, 258 259, 256 △△△△								
12. Control of Active Solar Space Conditioning Systems	SAN								275 △											

SYMBOLS: △ PLANNED ▲ COMPLETED ⨻ DELETED * KEY MILESTONE

SOLAR HEAT TECHNOLOGIES

SOLAR BUILDINGS TECHNOLOGY PROGRAM

DIVISION DIRECTOR : DAVID PELLISH

ACTIVITY	ORG	FY - 88												FY - 89						
		1st QTR			2nd QTR			3rd QTR			4th QTR			1st QTR			2nd QTR			
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	2 Half
III. DAYLIGHTING																				
1. Optical Switching Films	LBL								301* △			302 △	303 △							
2. Solid State Electrochromic "Smart" Windows	SAN											306* △								
3. Thermochromic Materials Research for Optical Switching Films	SAN												333 △							
4. Optics and Materials for Controlled Radiant Energy in Buildings	SAN									328 △			330*, 331 329 △△△							
5. Electrochromics	SERI															335* △				
6. Holographic Diffractive Structures for Enhanced Daylighting	SAN												324* △							
7. Evaluation of Photochromic Plastics	SAN											325* △								
8. Research and Development of a Static Optical System to Reduce Apparent Motion of the Sun	SAN								326 △			327* △								
9. Core Daylighting	LBL											337 △	338 313 △△							
10. Daylighting Technology Evaluation	LBL									340 △		341* 315* △△	342 △	343 △						
11. Atria	LBL									346 △	347 △		349 348 △△			350* △				

SYMBOLS: △ PLANNED ▲ COMPLETED ⩓̸ DELETED * KEY MILESTONE

SOLAR HEAT TECHNOLOGIES

SOLAR BUILDINGS TECHNOLOGY PROGRAM

DIVISION DIRECTOR : DAVID PELLISH

ACTIVITY	ORG	FY - 88												FY - 89						
		1st QTR			2nd QTR			3rd QTR			4th QTR			1st QTR			2nd QTR			
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	2 Half
IV. SYSTEMS INTEGRATION																				
1. Energy Absorbing Windows	SERI									401 △			402* △							
2. Systems Integration Research	LBL												404 △							
3. Design Tool Evaluation	SERI									405 △							407 406 △△			
4. Builder Guidelines	SERI												409 △	408 △						
5. IEA Task VIII: Technical Analysis -- Modeling and Simulation, Design Methods, and Design/Build Activities	SAN								413* △		414 △					455* △				
6. Development of an Industry Based Residential Building Thermal Performance Evaluation Program	SAN												451 △							
7. Short-Term Testing	SERI									416 △		460* △				461 △				

SYMBOLS: △ PLANNED ▲ COMPLETED ⨻ DELETED * KEY MILESTONE

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
101	10/88	SERI	Complete a conference paper and submit R&M results to SEIA.
102	12/88	SERI	Complete laboratory and field test plans simplified system development.
103	12/88	SERI	Complete a letter report on innovative system concepts.
104*	10/88	LANL	Complete five-year exposure tests and measure optical properties of glazings, selective coatings, and substrate materials.
105	10/88	SERI	Complete characterization of generic DHW and space heating system configurations.
106*	5/88	SAN/Chicago	Submit final report (86#222).(multilateral evacuated tube project)
107	7/88	SAN/Chicago	Submit annual research report.
108	9/88	SAN/Chicago	Experimental demonstration of the maintainability of high reflectivity of coating under conditions of bake-out of glass.
109	7/88	SAN/CSU	Annual research report on evacuated tube collectors, covering June '86 - May '87.
110	9/88	SAN/CSU/ICPC	Test and report performance of prototype tube.
111	9/88	SAN/CSU/ICPC	Coordinate and report the multilateral activity.
112*	8/88	SAN/Dayton	Topical research report on Phase IA covering development of improved fire-retardant capabilities in all major applications.
115	0/ 0	SAN/Nevada	Final technical report on thermal energy storage in plastic crystals as incorporated in building materials, Phase I.

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
125*	7/88	SAN/CBY	Completion of Volume 2 of Solar Thermal Energy Conversion.
126*	5/88	SAN/CBY	Completion of volume 8 of Solar Thermal Energy Conversion.
127*	12/88	SAN/CBY	Completion of volume 6 of Solar Thermal Energy Conversion.
128*	7/88	SAN/CBY	Completion of volume 9 of Solar Thermal Energy Conversion.
129*	9/88	SAN/CBY	Completion of volume 5 of Solar Thermal Energy Conversion.
130*	5/88	SAN/CBY	Completion of volume 3 of Solar Thermal Energy Conversion.
137	12/88	SAN/ETEC	Camera-ready copy to ASHRAE/SEIA.
138*	6/89	SAN/ETEC	IO&M manual published by ASHRAE/SEIA.
152	7/88	SAN/ETEC	Semi-annual program review.
153*	12/88	SAN/ETEC	Lessons learned.
154	12/88	SAN/ETEC	SFBP Solar System Monitoring Summary.
155	9/89	SAN/ETEC	Program Summary Report.
156	9/89	SAN/ETEC	All reports and program documentation complete.
157*	12/88	SAN/ETEC	Solar heating systems design manual published by ASHRAE.
158	0/ 0	SAN/CBY	Secure U.S. site for CSHPSS project.

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
160	9/88	SAN/CBY	Submit annual research report.
161	3/89	SAN	CSHPSS: University of Massachusetts phase 1 feasibility study report.
201	8/88	SERI	Modify two commercial polymers.
202	9/88	SERI	Complete testing of a novel desiccant/geometry configuration.
203	10/88	SERI	Synthesize one new polymeric structure.
204	11/88	SERI	Submit a journal or conference paper on results of a promising desiccant/geometry combination.
205	12/88	SERI	Complete a status report on results of desiccant contamination research.
206*	12/88	SERI	Complete a draft annual progress report on advanced desiccant materials.
207	3/88	LBL	Submit conference paper on comparative analysis of desicccant and absorption solar cooling systems.
208	9/88	LBL	Submit progress report on development of improved chiller simulation models as part of US/Israel joint project.
211*	11/88	SAN/ASU	Submit annual research report.
213	0/ 0	SAN/GMA	Submit annual research report.
214	9/88	SAN/Israel	Submit annual research report on simulation and analysis of high efficiency absorption systems for solar cooling.
216	7/88	SAN/FSEC	Submit DESRAD cycle and economic analysis.

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
228	6/88	SAN/ASU	Submit report entitled "Open-Cycle Absorption Systems Development". (FY 1986 milestone 614)
229	6/88	SAN/ASU	Performance of glazed collector/regenerator compared with unglazed C/R: Preliminary results.
232	6/88	SAN/ASU	Recommendation for purging technique.
233	5/88	SAN/ASU	Performance of glazed collector/regenerator compared with unglazed C/R: Final results.
234	8/88	SAN/ASU	Heat and mass transfer correlations for falling film absorber with non-absorbing gas: Non-absorbing gas concentration < 5%.
236	9/88	SAN/CSU	IEA Task VI - Prepare Task VI status report.
238*	9/88	SAN/CSU	House I - Complete analysis of system performance.
240	5/88	SAN/CSU	House II - Complete experimental data collection.
241*	9/88	SAN/CSU	House II - Complete analysis.
244	5/88	SAN/CSU	House III - Complete experiments.
245	9/88	SAN/CSU	House III - Analyze data.
246	0/ 0	SAN/GMA	Submit draft report. (FY 1986 milestone 621)
248	4/88	SAN/Israel	Add more absorption materials, such as LiCl + CaCl mixture and CaCl + ZnCl mixture to the computer model data bank.
249	7/88	SAN/Israel	Model and analyze GAX system.

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
253*	6/88	SAN/Wisc	Report on liquid desiccant cooling component performance.
256	8/88	SAN/IIT	Determine effective isotherm shapes in inert mass in the performance of solid desiccant systems.
257	8/88	SAN/IIT	Demonstrate heat and mass transfer in thick desiccant matrices.
258	8/88	SAN/IIT	Demonstrate enhanced heat transfer in solid desiccants.
259	8/88	SAN/IIT	Demonstrate enhanced transport of liquid desiccants.
260	6/88	SAN/FSEC	Technical Papers on Moisture Algorithms.
261	1/89	SAN/FSEC	Second year final report.
265	3/88	SAN/CSU	Submit annual research report on House I, covering June '86 - May '87.
270	7/88	SAN/CSU	Submit annual research report on IEA Task VI, covering June'86 - May '87.
271*	8/88	SAN/CSU	Annual research report on House III, covering June '86 - May '87.
275	5/88	SAN/Drexel	Final Report.
301*	5/88	LBL	Draft report "Failure and Degradation of Solar Materials".
302	8/88	LBL	Draft research report, sputtered counterelectrode materials for nickel oxide devices.
303	9/88	LBL	Draft research report, nickel oxide devices fabrication and analysis.
306*	8/88	SAN/EIC	Submit progress report on the development of a solid state device and related film research: complete development of an electrochromic device using DC sputtering, a process permitting devices to be manufactured at a faster rate. (FY 1986 milestone 108)

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
313	9/88	LBL	Letter Report: Assessment and Comparative Analysis of Core Daylighting System Options: Performance, Cost and Market Issues.
315*	8/88	LBL	Draft report on applications and performance requirements for aperture with optical switching technologies.
324*	9/88	SAN/AERG	Complete laboratory testing of photoresist hologram prototype: complete illustrative studies of holographic diffractive structures in architectural applications to establish functional requirements.
325*	8/88	SAN/AOC	Final report on evaluation of photochromic plastics: Phase I.
326	5/88	SAN/LSI	Submission of 10-6"x6" prototype lens samples.
327*	8/88	SAN/LSI	Final report describing in detail the performance of the final lens (including photometric test reports and the analysis results).
328	6/88	SAN/Tufts	EC Layer: Further improvement of reflectivity of WO_3, >80%.
329	9/88	SAN/Tufts	IC Layer: Develop conditions for reproducibly obtaining high electronic resistivity and lithium ion conductivity in multi-layer (device) applications.
330*	9/88	SAN/Tufts	CE Layer: Complete characterization and evaluation of In_2O_3 and V_2O_5.
331	9/88	SAN/Tufts	TC Layer: Minimize Li insertion into ITO.
333	9/88	SAN/Honeywell	Complete laboratory testing of a thermochromic paint: submit draft report describing research completed on thermochromic paint.
335*	12/88	SERI	Complete a year-end draft report describing work on PECVD to produceelectrochromic coatings and spectroscopy properties of WO_3 and MoO_3.

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
337	8/88	LBL	Progress Report: Design of Test Facility
338	9/88	LBL	Report: Design and Performance of a Core Daylighting System.
340	6/88	LBL	Tracking Milestone: Produce first aerogel sample for industry evaluation.
341*	8/88	LBL	Progress Report: Fenestration Materials Assessment.
342	9/88	LBL	Letter Report: New Technology Transfer Options.
343	10/88	LBL	Letter Report: Performance of existing and "smart" glazing materials in atria.
345	0/ 0	LBL	Submit Trip Report for trip to Cambridge (UK), identifying IEA contacts and planned collaborations (Annex XI,Subtasks A,B), US/UK contacts and planned collaborations, and descriptions of candidate buildings for daylighting performance evaluation project.
346	6/88	LBL	Submit letter report describing progress on the daylighting performance evaluation project, including instrumentation and analysis plans.
347	7/88	LBL	Submit letter report describing activities to date on atrium simulation development and support to other IEA participants (Subtask B).
348	9/88	LBL	Submit letter report describing activities to date in support of production of the "Design Tool for Roof Aperture Systems".
349	9/88	LBL	Submit interim report describing progress achieved in advancement of the daylighting performance evaluation of atria.
350*	12/88	LBL	Submit report fully describing the daylighting performance evaluation method (DPEM), including refinements incorporated to allow evaluation of atria. This report will be coordinated with the UK in order to submit a joint Advanced Case Study to the IEA.

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
401	6/88	SERI	Prepare a letter report documenting test results of a prototype window.
402*	9/88	SERI	Complete a letter report describing the model developed to predict performance.
404	9/88	LBL	Submit draft report on the energy use characteristics of selected building types by functions.
405	6/88	SERI	Participation in ASHRAE TC-4.7 standards subcommittee.
406	1/89	SERI	Participation in ASHRAE TC-4.7 standards subcommittee.
407	1/89	SERI	Prepare an ASHARE paper on the design tool verification procedure as modified according to needs of TC-4.7.
408	10/88	SERI	Develop a pilot expert version of the builder guidelines and supporting documentation.
409	9/88	SERI/PSIC	Produce prototype builder guideline packages for five locales.
413*	5/88	SAN/AEC	Complete camera-ready copy preparation of Design Information Booklets 1,2,4,5, and 8. (FY 1986 milestone 819)
414	7/88	SAN/AEC	Complete data collection, analysis, and reporting on two design/build passive solar projects.
416	6/88	SERI	Prepare and conduct seminar on short-term test procedures for buildings at June ASHRAE meeting.
451	9/88	SAN/NAHB-NRC	Field test the procedure for the estimation of the space heating efficiency of existing detached houses and similar small buildings and document the procedure.
455*	12/88	SAN/AEC	Complete camera-ready copy preparation of Design Information Booklets 3,6,7, and 9. (FY 1986 milestone 819)

SOLAR BUILDINGS TECHNOLOGY PROGRAM

1988 MILESTONES
July 1988

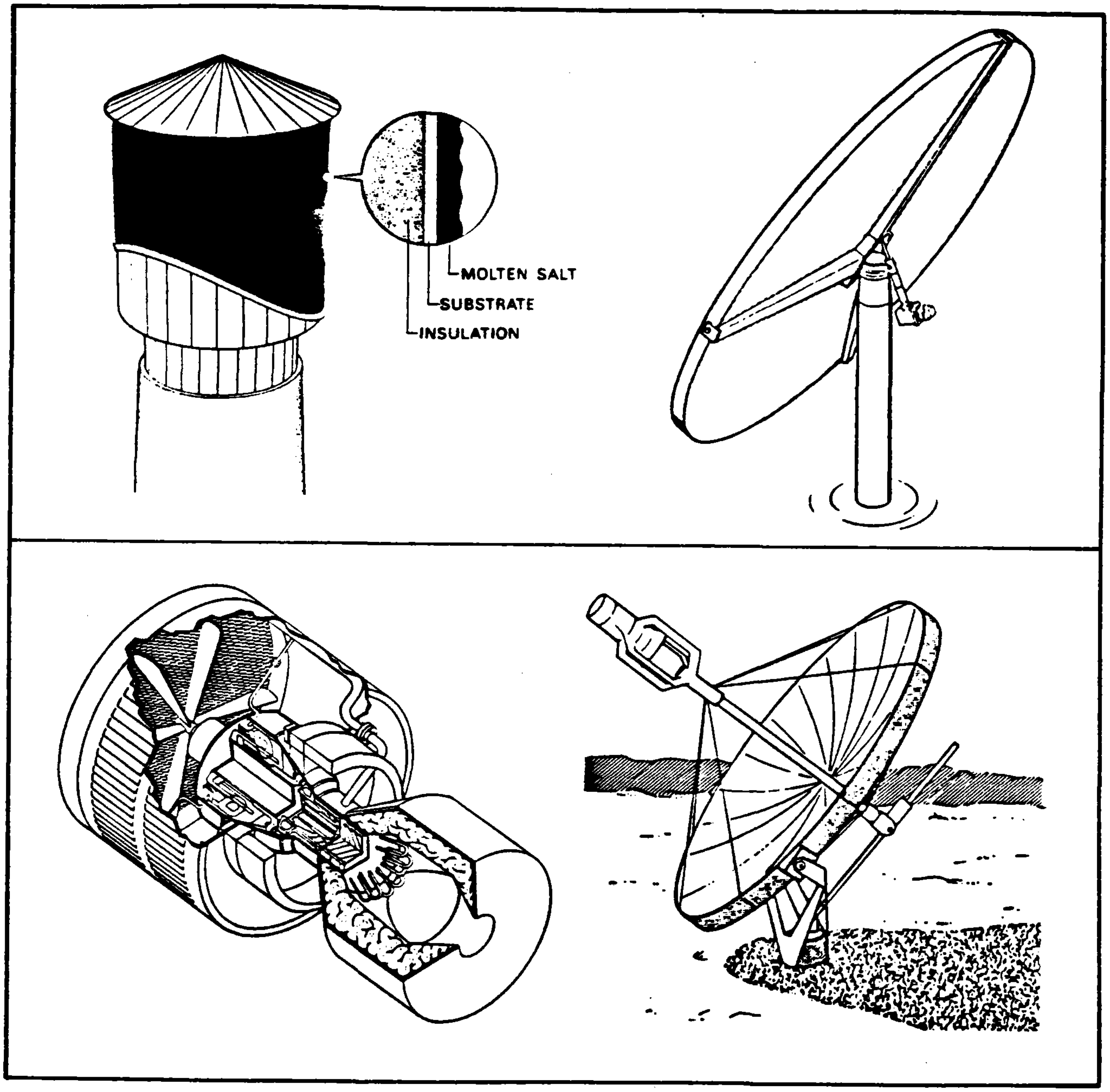
MILESTONE	DUE	LAB/CONTRACTOR	DESCRIPTION
460*	8/88	SERI	Develop STEM 2 microcomputer program and manual including draft report documenting STEM methodology.
461	12/88	SERI	Draft report describing test results, numerical simulation results, industry interaction/feedback and new developments.

APPENDIX II

FY [illegible] ANNUAL OPERATING PLAN

SOLAR THERMAL TECHNOLOGY PROGRAM

SOLAR THERMAL TECHNOLOGY
FISCAL YEAR 1988
ANNUAL OPERATING PLAN



MARCH 1988

Prepared for:

Division of Solar Thermal Technology
Office of Solar Heat Technologies
U.S. Department of Energy
Washington, D.C. 20585

Compiled by:

Meridian Corporation
and
Mueller Associates, Inc.
Alexandria, VA 22302

FOREWORD

The research and development described in this document is being conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The goal of the Solar Thermal Technology Program is to advance the engineering and scientific understanding of solar thermal technology, and to establish the technology base from which private industry can develop solar thermal power production options for introduction into the competitive energy market.

In solar thermal technology, tracking mirrors or lenses concentrate sunlight onto a receiver. The heat absorbed by the receiver has a variety of uses including conversion into electricity or use as process heat. The two primary solar thermal technologies, central receivers and distributed receivers, employ various point- and line-focus optics to concentrate sunlight. Current central receiver systems use fields of heliostats (two-axis tracking mirrors) to reflect the sun's radiant energy onto a single tower-mounted receiver. Parabolic dishes up to 17 meters in diameter track the sun in two axes and use mirrors or lenses to focus radiant energy onto a receiver. Troughs are line-focus tracking reflectors that concentrate sunlight onto receiver tubes along their focal lines. These concentrating collector modules can be used alone or in a multi-module system. The concentrated radiant energy absorbed by the solar thermal receiver is transported to the conversion process by a circulating working fluid. Receiver temperatures range from 100^{o}C in low-temperature troughs to over 1500^{o}C in dish and central receiver systems.

The Solar Thermal Technology Program is directing efforts to advance and improve promising system concepts through the research and development of solar thermal materials, components, and subsystems and the testing and performance evaluation of subsystems and systems. These efforts are carried out through the technical direction of DOE and its network of national laboratories, who work with universities and private industry. Together, they have established a comprehensive, goal-directed program to improve solar thermal technology performance and to provide technically proven options for eventual incorporation into the nation's energy supply.

To contribute successfully to an adequate national energy supply at reasonable cost, solar thermal energy must become economically competitive with a variety of other energy sources. To this end, components and system-level performance targets have been developed as quantitative program goals. The performance targets are used in planning research and development activities, measuring progress, assessing alternative technology options, and developing optimal components. These targets are being pursued vigorously to ensure a successful program.

This document is the Fiscal Year 1988 Annual Operating Plan (AOP) for the Solar Thermal Technology Program. The purpose of the AOP is to provide DOE Headquarters with a single, program summary document for use as a management tool. The AOP incorporates activities being conducted through a number of field offices and national laboratories that individually submit Annual Operating Plans to DOE for approval. These individual laboratory AOPs serve as control documents used by the Solar Thermal Technology Division within the DOE Office of Solar Heat Technologies for disbursement of funds under the Procurement Execution Plan. The program description, project funding, and milestone schedules shown for Fiscal Year 1988 are those in effect at the time of this document's publication.

CONTENTS

SOLAR THERMAL TECHNOLOGY
FISCAL YEAR 1988
ANNUAL OPERATING PLAN

I. INTRODUCTION AND PROGRAM OVERVIEW

A. Technology Description

Solar thermal energy systems concentrate the sun's radiation to generate electricity in thermal and thermoelectric cycles, produce high temperature process heat, and provide high radiant flux for use in various chemical reactions. The market potential for solar thermal technology is promising since it can produce electricity on a multi-megawatt utility scale as well as for small, modular applications. In addition, these systems can generate process heat in a wide range of temperatures for a variety of industrial applications. In the last decade, solar thermal energy generation has proven to be technically feasible in a series of successful experimental installations, and the costs of solar thermal systems have decreased significantly while their performance has steadily improved.

The three primary solar thermal technology concepts are central receivers (CR), point-focus parabolic dishes, and line-focus parabolic troughs. Groups of point-focus parabolic dishes and line-focus parabolic troughs where each reflector module has its own receiver are called distributed receiver (DR) systems. All three concepts employ the same principle of concentrating sunlight and are distinguished by the various mirror geometries and receivers utilized (Figure 1):

- Central receiver systems use fields of two-axis tracking mirrors called heliostats to reflect the sunlight onto a single tower-mounted receiver. Heliostats have been built in sizes up to 200 square meters. Systems containing more than 1800 heliostats of $40m^2$ and generating 10 MWe, have been constructed and successfully operated.

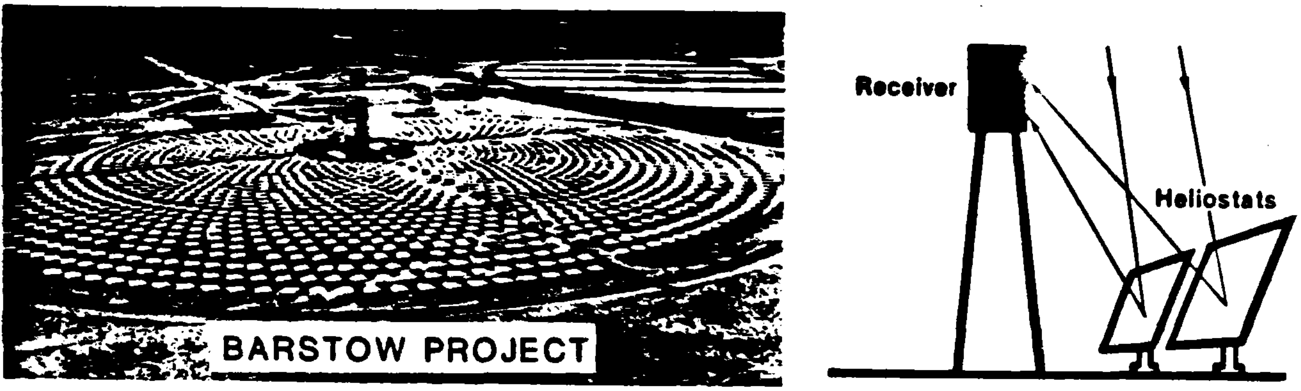
- Parabolic dishes use a two-axis tracking concept and focus the sunlight onto receivers/engines located at the focal point of each dish. Dish modules can be used in stand-alone or large multi-module systems. Systems containing over 700 dish modules and generating approximately 4.9 MWe have been constructed and successfully operated.

- Parabolic troughs use single-axis tracking collectors that concentrate sunlight onto a receiver tube positioned at the focal line of each trough. Individual trough modules can be combined in rows to meet large capacity needs. Parabolic trough systems collectively generating approximately 135 MWe are currently in operation. These systems make use of trough technology developed under the Solar Thermal Technology Program.

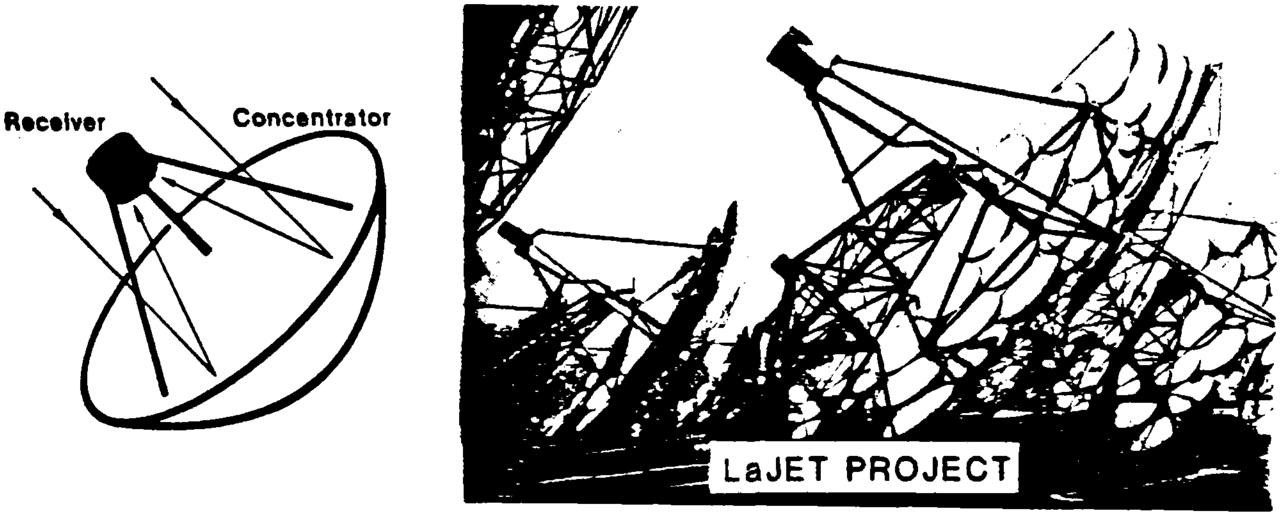
B. Program Goals and Objectives

To develop the balanced, flexible source of affordable and abundant energy mandated by the National Energy Policy Plan, the Solar Thermal Technology Program supports research and development (R&D) to improve cost and performance and broaden the areas of applicability of solar thermal systems. This ongoing R&D complements existing private industry efforts and will provide technically proven options for eventual incorporation into the nation's energy supply.

CENTRAL RECEIVER



PARABOLIC DISH



PARABOLIC TROUGH

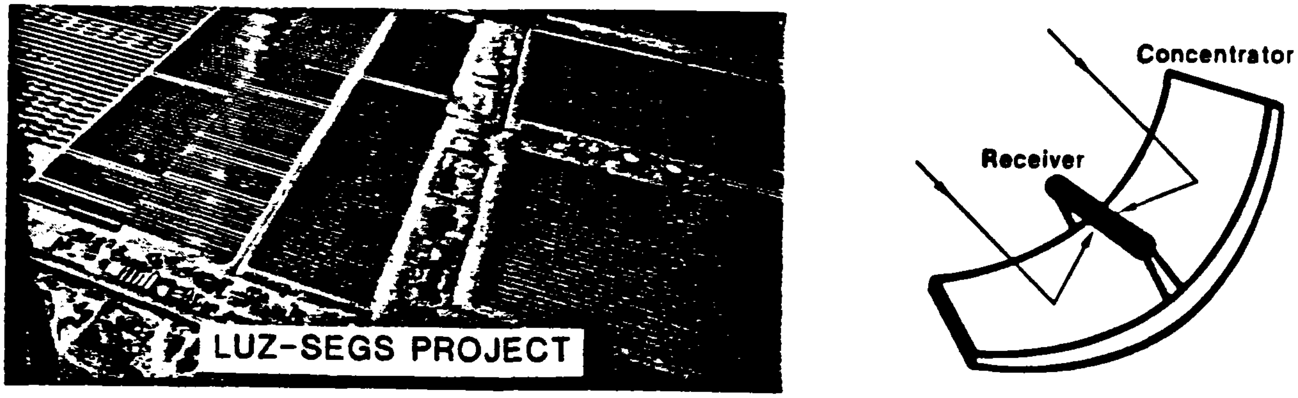


Figure 1.
SOLAR THERMAL TECHNOLOGIES

The Solar Thermal Technology Program goals are to:

- Develop high-performance, reliable solar thermal systems and components that will be competitive for electric and process heat applications;
- Develop technology for new applications using concentrated solar energy; and
- Assure technology exchange between the national laboratories, universities, and the private sector.

The objective of the Solar Thermal Technology Program is to conduct, in cooperation with the private sector, the research necessary to establish solar thermal technologies as viable energy supply alternatives. Mutual cooperation between industry and the Federal government is crucial to the success of the Program. Industry (suppliers and users) will benefit substantially from government-sponsored research and technology development efforts. In return, industry's cooperation and capability will help expedite solutions to the problems facing solar thermal technology and bring a more secure energy future to the nation.

C. Program Strategy and Thrust

The strategy of the Solar Thermal Technology Program is to pursue a goal-oriented, government-sponsored R&D program emphasizing activities which recognize the market penetration being made by parabolic troughs and which seek to develop systems and components which will improve systems' performance and economics. These R&D efforts will include activities to:

- Continue high-risk research on components for advanced systems including central receivers, dish Stirling, and parabolic troughs which have higher performance and lower cost.
- Seek industry, utility, and user community input to develop research plans and implementation strategies;
- Continue the established technology transfer efforts; and
- Pursue cooperative cost-shared efforts with industry/utility participants to achieve early technology/market penetration.

Electric applications are the primary thrust since this technology will be directly usable for most of the solar thermal process heat applications. Central Receiver systems and parabolic dishes using centrally located engines can be operated over 1000^{O}F utilizing maximum steam Rankine engine efficiencies. Stirling engines operating up to 1500^{O}F are available or are being developed for automotive and aerospace applications and are ideal for focus-mounted parabolic dishes.

Fifty percent of industrial process heat applications require a temperature of 1100^{O}F or lower. Only 10% require temperatures in the range of 1100^{O}F to 2400^{O}F. Process heat applications above 2400^{O}F are dominated by the utilization of in-process electric heaters. Economic utilization of Solar Thermal Technology for process heat (non-electric) above 1100^{O}F requires a unique photo/thermochemical advantage.

Figure 2.

SOLAR THERMAL TECHNOLOGY ELECTRICITY COST TRENDS

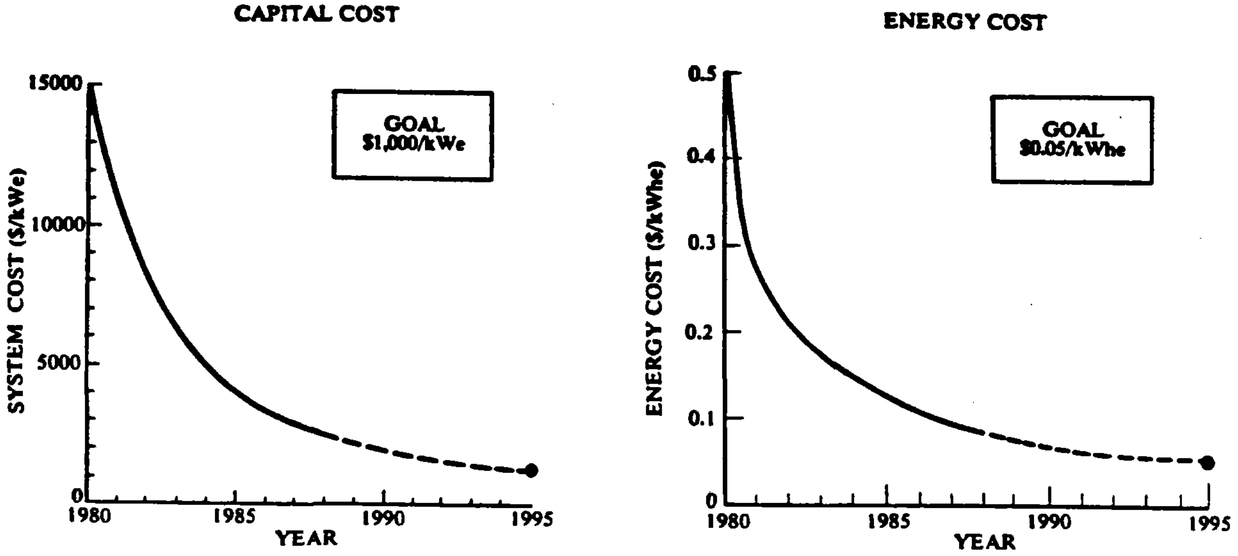
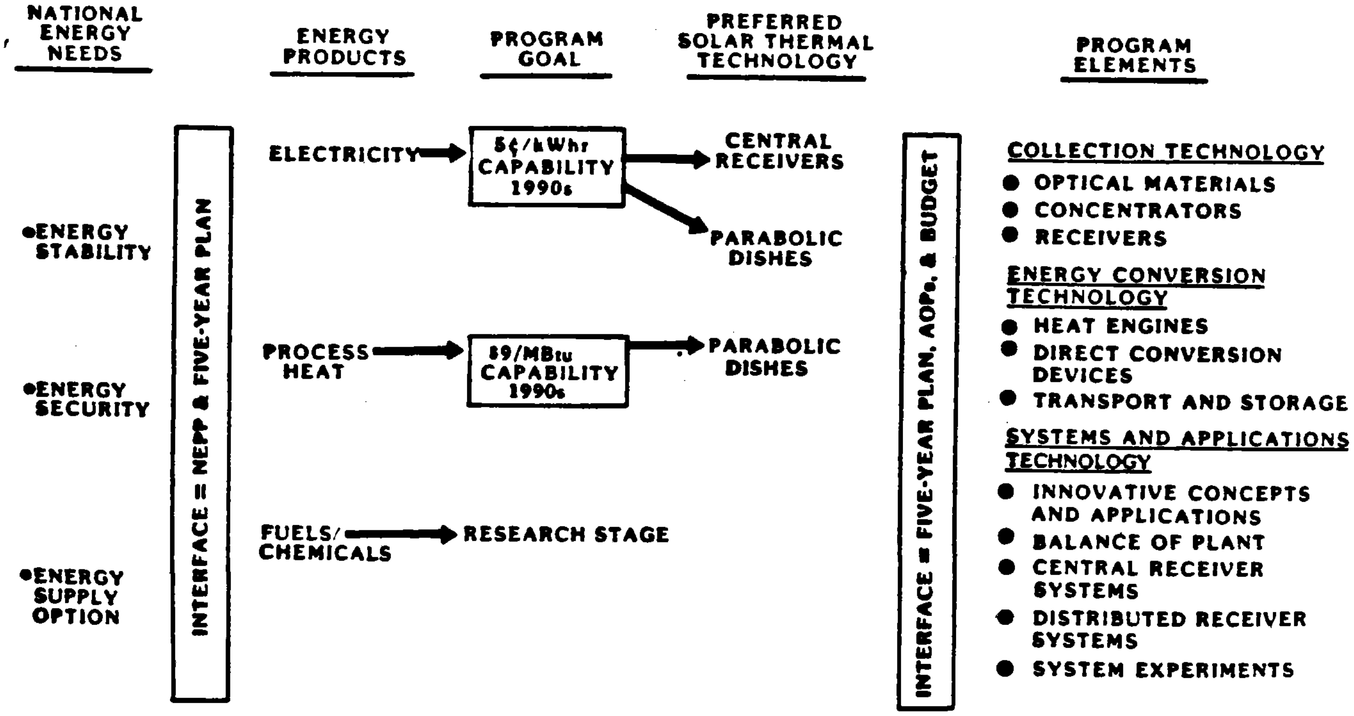


Figure 3.

NATIONAL NEEDS ⇨ PROGRAM ELEMENTS



D. Solar Thermal Multi-Year Program Plan Summary

The primary document for long-term program planning is the National Solar Thermal Technology Program Five-Year Research and Development Plan (1986-1990). The Plan establishes overall program goals consistent with national energy policy and provides both five-year and long-term quantified component goals, program schedules, and task descriptions. Specific system-level performance and cost goals are key elements of the five-year plan. Current system designs have an annual efficiency of about 15% and a capital cost of about $3000/kWe for CR, and 20% and $3000/kWe (peak) for DR for first plants. Further cost reductions are possible through production of three or more plants to potentially make solar thermal technology cost-competitive for the late-1990 utility market, including peaking and intermediate load generation for CR, and peaking, intermediate, and remote applications for DR. Long-term goals call for system capital costs below $1200/kWe and system energy costs below 5¢/kWe. During the 1980s, the program has reduced both capital and energy costs by 80%, according to recent estimates by utilities. (Figure 2.) To reach these goals, components and systems having higher efficiency, performance, and reliability, as well as lower cost, are being developed.

These system cost goals can be used to evaluate the potential contribution of different system configurations using available technology options. Since systems are made up of groups of components, system level targets can be used to derive ranges of allow able component performance/costs. Obstacles to meeting these system and component performance and cost goals help define future R&D requirements. This approach has lead to the development of a Solar Thermal Technology R&D program comprised of 11 tasks which deal with issues related to exploratory development (innovative concepts, direct conversion devices), sub-component research (optical materials), component development (concentrators, receivers, heat engines, transport and storage, and balance of plant), and system analysis and proof-of-concept experiments (central receiver systems, distributed receiver systems, and system experiments). The solar thermal technology program approach to develop goals, objectives, and appropriate strategy is represented in Figure 3.

II. TECHNOLOGY PROGRESS AND STATUS

A. Technology Progress

The Program goal of economically competitive energy production from solar thermal systems is being cooperatively addressed by industry and government. Significant progress has been made towards achieving economically viable solar thermal energy generation for electrical and industrial process heat applications. Vigorous R&D efforts in the past decade have improved the performance and reliability of solar thermal systems and contributed toward reductions in the cost of delivered energy. The continued successful operation and data collection from experiments, such as the 10 MWe Central Receiver Pilot Plant (Solar One) in Daggett, California, and the Solar Total Energy Project (STEP) in Shenandoah, Georgia, is diminishing the uncertainties and risks associated with system performance, operation, and maintenance. Furthermore, efforts to encourage more involvement from industry and the utility sector, such as LaJet's Solarplant 1 and the Luz Solar Electric Generating Stations (SEGS), have helped to increase R&D efforts in solar thermal technology.

Numerous field test installations using parabolic trough technology have been built and operated successfully, and analysis of their performance has provided valuable O&M information and guidance. Parabolic trough systems have shown significant cost reductions and performance improvements. Luz Engineering Corporation has successfully applied trough technology, including cermet coating and polymer film technology developed under the Solar Thermal Technology Program, to a large scale commercial application in their Solar Electric Generating Station (SEGS) projects located at Daggett and Kramer Junction, California. The success of experiments sponsored by DOE combined with private industry efforts has resulted in commercial readiness of the parabolic trough technology.

1. Central Receiver Progress

Central receiver research and development efforts include the development of designs, the analysis of system parameters, and the experimental testing of components or groups of components. Solar One has demonstrated the concept of electric power production using a steam-Rankine conversion cycle with water/steam serving as the receiver heat transfer fluid. Solar One has provided valuable operation and maintenance experience to the utility plant operators through a 3-year power production phase (August 1984 to August 1987). Solar One is currently being operated in a semi-commercial mode by the utility owner and will provide additional data on revenue optimization from a solar thermal central receiver plant. In Albuquerque, New Mexico, the Central Receiver Molten Salt (Category B) Experiment is evaluating the technical and economic feasibility of using molten salt as a heat transfer fluid by testing specific critical components, such as the pumps, valves, and receiver. In addition, a group of southwestern utilities is studying the appropriate path to the next generation of central receiver technologies in utility applications, and has selected conceptual designs for 100 MW_e plants utilizing molten salt receivers and stressed membrane heliostats. At the International Energy Agency's (IEA) Small Solar Power Systems (SSPS) Project in Almeria, Spain, a number of countries, including the United States, have participated in the testing of a 500 kWe central receiver system using sodium as the heat transfer fluid.

In recent years, research and development on central receiver components and systems has resulted in significant cost reductions based upon improved designs and operational experience. Individual heliostat costs have decreased from over $\$1000/m^2$ to current quotes of less than $\$150/m^2$, while at the same time the reflectivity of mirror surfaces has increased from 70% for early systems to over 90% today. Major developments in heliostat technology have proceeded along two primary fronts: large area glass/metal mirrors and stretched membrane heliostats. Both concepts show significant potential for further cost reductions. In the last year, testing of two large area glass/metal heliostats was conducted and very encouraging preliminary results have been obtained during testing of prototype stretched membrane heliostats. Testing of large area heliostats will be completed during FY1988 and two improved stretched membrane prototype heliostats will be designed and fabricated.

Research has also shown that improved system performance and lower costs can be achieved with heat transfer fluids, such as molten salts, that have better heat transfer characteristics than water and that can also be used for thermal energy storage. In this area, substantial progress is being made through design and testing of molten salt subsystems and components in the Category B Experiment mentioned above. Ultimately, central receiver technology may also benefit greatly from the higher temperatures, solar flux levels, system efficiencies and lower costs which could be achieved with direct absorption receivers (DAR). Recent progress in development of this technology has included the design of a 3 MWt solar Panel Research Experiment (PRE) to allow flow testing with molten nitrate salt and to provide a test bed for DAR testing with actual solar heating. The system is capable of operating at flow conditions similar to a commercial-sized DAR and is being designed for easy replacement of panels and manifolds to allow testing of different configurations. In addition, research is continuing to characterize flow conditions of molten salt DAR and to investigate alternative blackeners for use in DAR systems.

Overall, advances in performance and reductions in component costs have reduced delivered energy costs, while increased reliability and system operating experience has significantly reduced operation and maintenance (O&M) expense and downtime. These system advances and cost savings have decreased overall energy costs from $1.25/kWhe to an estimated $0.13/kWhe (levelized in real dollars) for currently proposed solar electric power generating systems. During FY1987, independent utility teams conducted studies to determine the best state-of-the-art configuration for future solar central receiver electric plants in utility service. The preferred configuration for the solar power tower was established based on these studies and projections of the cost to produce electricity were estimated at $0.08 to $0.10/kWhr (levelized cost).

2. Distributed Receiver Progress

Significant progress has been made as a result of past research and development work in distributed receiver technology, which is comprised of parabolic dish and parabolic trough concepts. Parabolic dish electric power production has been evaluated for lower temperature (less than 600°C) Rankine-cycle systems using water/steam or organic working fluids. For example, the 3 MWt system at Shenandoah, Georgia, operational since 1982, uses parabolic dish modules to heat a silicone-based fluid to provide process heat, air conditioning, and electric power. Two experiments are planned to evaluate solar electric plants in a small community utility environment. A data system will be installed at both the Osage City and Molokai sites to obtain weather and operational data for each small community solar experiment.

Current parabolic dish designs are evolving toward higher operating temperatures (up to 1370°C) to take advantage of their high solar flux concentration capability. The most notable progress for parabolic dish systems with heat engines at the focal point has been the achievement of higher receiver operating temperatures for electric conversion processes, resulting in increased overall system efficiency. A record of 31% gross (29% net) energy conversion of sunlight into electricity was achieved during 1984 using a focal-mounted Stirling-cycle engine in an advanced Vanguard dish module. Work continues on advanced power conversion cycles with recent advances in free-piston Stirling and thermoelectric conversion R&D. The reflux receiver concept has been identified as a potential receiver option for kinematic and free-piston Stirling engines and thermochemical transport. The reflux concept promises simple, low-cost, reliable, and efficient receivers and readily permits fossil fuel hybridization. A contract was placed in FY1987 with Stirling Thermal Motors (STM) Inc. for a reflux receiver to operate the STM 4-120 engine.

Similar to the central receiver technology, dish systems will also benefit from recent advances in stretched membrane and other low-cost concentrator technologies. Research has identified major structural/optical response parameters indicating that high quality optical membrane surfaces are feasible from a structural perspective, and that a vacuum can be used to stabilize the membrane into the desired shape while minimizing the effects of wind and weight. A two-meter diameter mesh

membrane dish was completed in FY1987. The surface quality and overall shape of the membrane were much better than earlier prototypes.

The parabolic trough concept is the most developed of the three major solar thermal technologies. It has a well-defined range of industrial process heat/steam applications at temperatures below 400°C. Numerous field test installations have been built and operated successfully, and analysis of their performance has provided valuable O&M information and guidance. Parabolic trough systems have also shown significant cost reductions and performance improvements. Today's collectors have raised the peak performance standards into the 60% peak efficiency region by increasing concentrator accuracy and incorporating silvered glass reflector technology. Costs for these systems are currently less than \$400/m^2 of installed collector aperture. Luz Engineering Corporation has been successful in applying trough technology which makes use of concepts developed under the Solar Thermal Technology Program to a large scale commercial application in their Solar Electric Generating Station (SEGS) projects located at Daggett and Kramer Junction, California.

B. Technology Status

The Solar Thermal Technology Program is structured into 11 major R&D task areas, each specifically directed toward achieving the program goals and planning targets. Descriptions of each of the major task areas are provided below, along with a brief summary of their current technical status.

1. Collection Technology Status

In the solar thermal process, collection encompasses the concentration of the sun's radiant energy and its absorption as thermal energy by the heat transfer fluid in the receiver. The R&D tasks within collection technology are optical materials, concentrators, and receivers.

- Optical materials are an integral part of any concentrator and receiver, however, their performance is so critical to cost reduction that a separate task has been allocated to develop low-cost, light-weight, durable optical reflector materials.

- Since concentrators are one of the largest single cost elements of a solar thermal system and their performance has such a strong effect on overall system efficiency, their development will continue to receive emphasis within the Solar Thermal Program.

- Receivers also play a major role in system efficiency and applications selection, and offer a potential for significant reduction in overall system cost. Receiver material and fabrication techniques determine the system temperature limitation, while optimum design configurations can minimize thermal losses.

Task 1. Optical Materials

Optical materials research is largely directed towards the development of improved reflectors. The objective of reflectors research is to obtain reflecting surfaces that achieve high specular reflectance (reflectivity greater than 90%, maximum specularity of 4 mrad) at low-cost (\$15/m^2), and can satisfactorily operate in the solar environment over extended periods of time. Research is focused on the development of high durability, highly reflective silver/polymer reflective surfaces and thin foil stainless steel reflectors (using the sol-gel process); development of advanced reflector concepts such as structural membrane composite materials and high flux reflectors; and development of effective methods for minimizing the efficiency losses of large area heliostats and dishes due to soiling.

Technology status highlights:

- Stable silver/polymer films have been produced which exceed long range goals for initial specular reflectance. Continued work and testing is required to demonstrate that this performance can be maintained for the five-year life goal. Outdoor weathering results from accelerated and real-time testing show that in environments like Golden, Colorado, the silver can be protected from corrosion for at least three years and full optical performance (reflectance of 90% at 4 mrad) is maintained for at least 1 1/2 years.
- The Large Aperture, Near Specular, Imaging Reflectometer (LANSIR) is in operation at SERI and allows for scattering measurements on samples as large as 37 cm in diameter.
- A subcontract was placed with Industrial Solar Technology to collect real-time data on soiling and cleaning of an operating concentrator field in Brighton, Colorado. In addition, a 36 sq. ft. exposure rack has been constructed to obtain data on new materials and glass.
- The development of sol-gel has made it possible to take advantage of the inherently high reflectivity of silver by placing a protective coating of sol-gel over the silver reflective surface.

Task 2. Concentrators

Concentrators are a critical element in a solar thermal system. Concentrators must track the sun and efficiently reflect the incident radiation. Because the cost and performance limits for optimized concentrators using state-of-the-art silvered-glass technology are relatively well defined, further significant reduction in concentrator cost depends on the development of new concepts, such as the stretched membrane concentrator, light-weight, low-cost reflective surfaces, and low-cost drive systems.

Central Receiver Concentrator Technology Status

Large area glass/metal heliostats and stretched membrane heliostats are two alternative designs for heliostat development. Analyses have indicated that present glass/metal heliostats approach a minimum cost of \$80/m^2 at a cumulative production of a million units. Large area glass/metal heliostats make use of existing materials technology while producing cost reductions throughout the concentrator subsystem through economies of scale. Stressed membranes have the potential of a 75% weight reduction of the reflector and support structure and a 50% reduction in heliostat production cost over current glass/metal heliostats. Cost goals in the range of \$40/m^2 appear achievable for stressed membrane heliostat technology. As concentrator costs are reduced, drive mechanisms will become a more dominant cost element. Research is underway to develop new, low-cost drive mechanisms to be used in conjunction with low-cost stressed membrane concentrators.

Technology status highlights:

- Over 2,130 first-generation heliostats have been built and tested (222 of 37m^2 each at the Central Receiver Test Facility (CRTF); 93 of 39m^2 each at IEA-SSPS Almeria, Spain; and 1818 of 40m^2 each at Solar One).

- At ARCO's oil recovery plant at Fairfield, California, 30 ARCO $57m^2$ second-generation heliostats are in operation. ARCO has also built and tested $95m^2$ and $150m^2$ prototype glass/metal heliostats.* Under license to ARCO, Advanced Thermal Systems is continuing development of large area glass/metal heliostats and is testing a $150m^2$ heliostat at the CRTF. A $200m^2$ glass/metal heliostat developed by Solar Power Engineering Company (SPECO) has been installed and testing initiated at the CRTF during FY1987.

- SAIC and SKI have completed detailed designs of $150m^2$ stressed membrane heliostats and fabrication of $55m^2$ prototypes. These prototypes have been installed and tested at the CRTF during FY1987. Contracts are in place with the two contractors for further development, which will emphasize improving the design of a mass-producible, commercial heliostat, and will provide for construction of two more prototypes (one from each contractor).

- Peerless-Winsmith has designed a new low-cost drive mechanism, and has initiated fabrication of prototypes.

Parabolic Dish Concentrator Technology Status

Present glass/foamglass parabolic dish concentrators have high concentration ratios but are heavy and costly. If a low-cost/high-performance reflector is incorporated with an optimized structure, parabolic dish concentrators have the potential of being cost-effective. Like heliostats, stretched membranes for parabolic dish technology have the highest potential for reducing overall concentrator costs, and a major effort is currently underway.

Technology status highlights:

- At the Solar Total Energy Project at Shenandoah, Georgia, 114 dish concentrators each 7-meters in diameter and utilizing an aluminized reflective film are in use.

- The German-Saudi Energy Corporation has developed a 17-meter diameter ($227m^2$) vacuum-controlled metal membrane dish concentrator using 0.6mm glass mirror facets bonded to the steel membrane. One concentrator is being tested in a solar village site near Riyadh, Saudi Arabia.*

- LaJet Energy Company has developed a low-cost 1.4m diameter stressed aluminized-metal membrane reflector with its shape controlled by vacuum.* At LaJet's Solarplant 1, 700 dishes utilizing these reflectors are currently in use.

- Under the Innovative Point-Focus Solar Concentrator (IPFSC) program, both LaJet Energy Company and Acurex Corporation have completed prototypes.

- Contracts have been awarded to LaJet Energy Company and Solar Kinetics, Inc. for the conceptual development of stretched membrane dishes. Under these contracts, both single- and multi-facet concepts showing improved optics and lower cost are being developed. The Phase I design reviews were conducted during FY1987.

Parabolic Trough Concentrator Technology Status

Successful completion of DOE-sponsored Modular Industrial Solar Retrofit (MISR) project and Industrial Process Heat (IPH) experiments combined with the private industry efforts has resulted in

---

*Non DOE Solar Thermal Technology funding.

commercial readiness of the parabolic trough technology. No further R&D is planned under DOE solar thermal technology program.

Luz Engineering Corporation has been successful in applying trough technology to a large scale commercial application in their Solar Electric Generating Station (SEGS) projects in Daggett and Kramer Junction, California. SEGS I-V* are now on-line with rated capacity of approximately 135 MWe. Purchase contracts with Southern California Edison for additional SEGS units have been signed, making this the largest single privately-funded project employing solar thermal technology in the world.

Other Concentrator Research

Several other areas associated with concentrator development are being addressed by the solar thermal research program. A critical problem facing designers of large area concentrators is the effect of wind loadings. Continued research has focused on the fundamental wind loads on both isolated and fields of dishes. With reductions in weight and wind loadings, concentrator structural elements may be able to utilize lower cost composite materials. While secondary concentrators have the greatest benefits with either low-quality or high-temperature dish systems, there are also some potential benefits with high-quality dish systems including increased tolerance for tracking, decreased sensitivity to many design parameters, and an increased flexibility in system design.

Technology status highlights:

- Colorado State University and SERI have been conducting wind tunnel tests to study wind loadings on solar concentrators and wind effects mitigation techniques.
- Dish membrane studies have been conducted by SERI to assess frame/membrane structural impacts on surface distortions and to predict optical performance impacts which are induced by defined membrane shape distortions.
- A two-meter diameter module fabricated by SAIC demonstrated the feasibility of using composite materials and of obtaining potentially high-quality, low-cost membrane dish reflectors using composite materials. Experimental results on materials samples made from the prototype membrane materials have shown that specularity of the reflector stack is roughly 3 milliradians (one standard deviation).
- The University of Chicago has completed a report (SERI/STR-253-3113) documenting studies of the performance and cost benefits of secondary concentrators for dish concepts. The report concludes that it is theoretically possible to achieve a concentration of 70,000 suns, which would expand opportunities for high flux applications. The report also suggests that secondary concentrators may present a cost-effective alternative to very high quality surfaces for primary concentrators.
- The University of California, Berkeley, has completed a study on the application of composite materials for heliostat structures and reflective membranes which showed that savings in weight are achievable even when low-cost composites are used for the frame. The study also showed that the use of graphite composites reduces the deflection of the frame considerably.

---

*Non DOE Solar Thermal Technology funding

Task 3. Receivers

Receivers are the components that convert solar radiation into thermal energy. To date, receivers have been built and tested using heat transfer fluids such as oil, water/steam, molten nitrate salt, liquid sodium, and air. Most of these receivers operate at temperatures below 800°C, with annual efficiencies between 75% and 90%. Current costs of receivers (expressed in dollars per square meter of concentrator aperture area and including the tower in the central receiver case) are as low as $\$80/m^2$ for central receiver systems and $\$40/m^2$ for distributed receiver systems. The long-term goals are to reduce these costs to $\$30/m^2$ for both central and distributed receiver systems.

Central Receiver (CR) Receiver Technology Status

Central receiver research is focused on finding the best cost/performance receiver for applications up to 600°C. This temperature range is a main element in the near-term technology development thrust. Receiver research and development also has the goal of extending the temperature capability of central receivers to 800-1000°C with up to 90% efficiency. Receiver working fluids include water/steam, nitrate salts, and sodium. Receivers utilizing water/steam are the most technically developed, but are costly due to the high pressure design requirements of the receiver, piping, pumps, and heat exchangers. Also, turbine performance and system capacity are reduced due to the low pressure/temperature storage limitations of the receivers. Sodium receivers can be designed to high heat fluxes that minimize weight. Sodium is also an excellent heat transfer fluid; however, it is expensive and difficult to contain. For these reasons, the use of liquid metal sodium as a receiver heat transport fluid has been ruled out by the Utilities Study in favor of molten nitrate salt. Nitrate salt is a good low pressure heat transfer fluid, but it has a high melting point and therefore requires draining and/or trace heating throughout the system to prevent salt freezing (280°C to 600°C operating range). The Molten Salt Subsystem/Component Test is directed at the resolution of technical uncertainties currently associated with conventionally designed molten salt-in-tube receivers, subsystems and components. This work provides a sound technological base for development of molten salt central receiver systems and supports the design and construction plans for advanced central receiver plants. Major cost and performance improvements to receiver technology can be achieved by use of a Direct Absorption Receiver (DAR) concept. The DAR is the current receiver concept that promises to achieve the long-range program goals. In FY1987, a complete review and analysis of the nitrate salts for DAR to 800°C in the presence of air was performed and assembled strong evidence that the accelerated corrosion of metals in such salt above 600°C was due to temperature effects on the chemistry of the protective oxides rather than simply on changing chemistry of the salt. DAR systems studies and basic receiver element testing will continue during FY1988.

Technology status highlights:

- A 10 MWe water/steam external receiver has been evaluated as part of the Solar One Barstow Project at Daggett, California.

- A 5 MWt sodium cavity receiver has been tested at the CRTF as part of the Molten Salt Electric Experiment (MSEE), and a 0.5 MWe sodium receiver has been operated at the IEA-SSPS, Almeria, Spain.

- Experiments using the DAR Inconel test loop at SERI have been conducted to assess the impact of blackeners on salt stability and metal corrosion. At temperatures up to 500°C, cobalt oxide blackeners have been shown to have no impact on corrosiveness of nitrate salt against Inconel and stainless steel.

- Installation and optical characterization of the 5MWt Subscale Molten Salt Receiver at CRTF have been completed. Testing will continue into FY1988 as part of the "Category B" industry/DOE cost-shared molten salt experiment.

- A Handbook for Solar Central Receiver Design (Sandia report number SAND 86-8009) has been completed which incorporates information about the latest technology developments and test results from central receiver research. This handbook can be used by industry to prepare conceptual designs and commercial cost estimates.

- Experiments to assess the behavior of nitrate salt films for use with DAR systems have been performed by SERI. The results indicate that the stability of nitrate salt in DAR environment appears quite satisfactory to 750°C. This provides added flexibility in DAR operating conditions and makes the occasional occurrence of hot spots above 600°C insignificant to the long-term operation of DAR.

- Sandia National Laboratory has completed construction of a large-scale (10m in height by 2m in diameter) water flow test apparatus. The large-scale experiment is designed to investigate DAR development concerns such as wind effects, multizone flow effects, and wave phenomena for long vertical films, which cannot be addressed on a smaller laboratory-scale apparatus.

Distributed Receiver (DR) Technology Status

The receiver is a key component of a distributed receiver system. Its design must meet the requirements imposed by the concentrator and the power conversion or thermal process subsystem. For example, dish receivers can be used to supply heat to a power-conversion unit (such as Rankine or Stirling) for the production of mechanical power or electricity, or they can be used in the production of process heat. The long-term goal is to develop receivers with 90% to 95% efficiencies that can be manufactured for $30/m^2 of concentrator aperture area.

Energy losses from receivers have typically been higher than expected. It has become evident that improved receiver performance can be a cost-effective way of improving system performance. Therefore, efforts are being directed at identifying and reducing the various energy losses.

A significant development in FY1986 was the evolution of the "reflux" receiver concept that utilizes a boiling metal such as sodium as an intermediate heat transfer fluid. Unlike a conventional heat pipe, the evaporator section is shaped to optimize the collection of solar energy, and condensed sodium is returned to the evaporator by gravity. Analysis of preliminary designs indicates that simple, low-cost, reliable, efficient receivers are possible with potential applications for kinematic and free-piston Stirling engines, and thermal electric energy conversion devices. In addition, the reflux concept readily permits fossil fuel hybridization. Testing on the reflux receiver will be performed at the Weizman Institute of Science under a bilateral agreement with Israel.

Technology status highlights:

- A dish receiver for an organic Rankine cycle (ORC) engine has been developed and is undergoing testing for use at the Small Community Solar Experiment #1 at Osage City, Kansas.

- At the Solar Total Energy Project at Shenandoah, Georgia, 114 dish receivers using a silicone-based heat transfer fluid (Syltherm) are being operated.

- A dish receiver for a Stirling cycle engine has been tested and evaluated on the Vanguard Project at Rancho Mirage, California. The results achieved a record conversion efficiency for sunlight to electricity (31% gross, 29% net).

- A 20kW thermochemical reflux receiver/reformer built by Sandia began testing at the Weizmann Institute of Science, Israel, as part of a United States-Israel bilateral agreement.

- The detailed design for the STM 4-120 reflux heat-pipe solar receiver has been completed by Stirling Thermal Motors. Connection of the receiver will be completed in FY1988.

2. Conversion Technology Status

Conversion technology includes processes and components to convert the thermal energy provided by the receiver into electrical, mechanical, or other usable energy forms such as energy-intensive fuels and chemicals. It also includes thermal energy storage and thermal or thermo-chemical processes for transporting energy. In addition, it includes heat exchangers (the devices that allow heat transfer between the receiver, transport, and storage subsystems), heat transport systems, storage, and end-use applications.

The principal tasks for this area are adaptation of heat engines for dish electric applications, investigation of direct conversion devices, and development of low-cost, high-efficiency energy transport and storage.

Task 4. Heat Engines

Heat engines are thermodynamic devices that convert thermal energy to mechanical energy, which can then be converted to electricity. An engine's conversion efficiency directly impacts the total system efficiency and, hence, is a major concern. Capital cost, maintenance expenses, and lifetime are also important concerns. Program goals for engine performance and cost in the long-term are 41% annual efficiency and $300/kWe to support the system-level goal of $0.05/kWhe.

Heat engine comparison studies conducted in the past suggest that dish electric systems that use free-piston Stirling engines have a good chance of meeting long-term solar thermal cost goals since they offer the potential of high reliability, long life, low maintenance, and high cycle efficiencies. Kinematic Stirling engines mounted at the focal point of dishes have already achieved high operating temperatures, resulting in increased electric conversion efficiency. Kinematic Stirling development has progressed to include variable swashplate configurations, as in the current STM 4-120. Small Rankine cycle engines can also be mounted at the focal point of dish electric modules. Four of these Rankine cycle modular systems will be used for the Small Community Solar Experiment #1 at Osage City, Kansas. Regenerative Thermoelectrochemical Converters (RTEC) use concentrated solar flux directly and have a potential for up to 40% heat-to-electric conversion efficiency, a low initial cost, low maintenance, modularity, and the possibility of low temperature, and low-cost chemical storage. Research will continue to focus on acquiring the experimental and theoretical knowledge necessary for understanding some of the more complex and fundamental phenomena in order that a conceptual configuration of the receiver/regenerator can be determined.

Technology status highlights:

- An organic Rankine cycle engine to be used for the Small Community Solar Experiment #1 at Osage City, Kansas began testing at the DRTF in FY1987.

- A 25 kWe kinematic Stirling engine (USAB 4-95) has undergone performance and life tests on the Vanguard Project. A 50 kWe (USAB 4-275) engine is undergoing performance and life tests on the 17m diameter metal membrane dish concentrator at the German-Saudi Energy Corporation site at Riyadh, Saudi Arabia.* A derivative of the USAB 4-95 Stirling engine producing 25 kWe was coupled with a McDonnell Douglas concentrator module and was installed for testing at Southern California Edison and Georgia Power Company test sites.

---

*Non DOE Solar Thermal Technology funding.

- Mechanical Technology, Incorporated (MTI) and Stirling Technology Company (STC) are developing 25 kWe free-piston Stirling engines under a NASA contract. Preliminary and final concept designs have been reviewed.

- Stirling Thermal Motors has initiated fabrication of a swashplate kinematic Stirling engine and reflux receiver system. Delivery of the engine to the DRTF for testing is expected in early FY1988.

Task 5. Direct Conversion Devices

The objective of this task is to define and validate the feasibility of using high flux solar radiation (at least 250 watts/cm^2) to initiate and sustain endothermic chemical reactions. The unique features of concentrated solar radiation relative to fossil fuel are the ability to produce high temperatures, the ability to heat rapidly, and the existence of high energy photons in the short wavelength region of the solar spectrum. These features can be utilized to initiate endothermic chemical reactions. The effects of solar-unique or solar-beneficial have been observed experimentally, including the enhancement of detoxification of hazardous wastes and observation of significant shifts in chemical reaction rate and selectivity. In addition to conversion to thermal energy, concentrated solar energy provides a controllable means of delivering large flux densities of wideband radiation to solid surfaces. Since conversion of radiant energy at the surface is direct, the usual losses from heat exchange in solar electric conversion are avoided. Use of the solar resource for some materials processing may already be economically competitive, and large solar furnaces may prove to be ideal resources for certain applications in materials processing. The main emphasis will be on applications with materials of strategic significance, composites, ceramics, and wear, heat, and corrosion resistant coatings.

Technology status highlights:

- Researchers at the Georgia Tech Research Institute (GTRI) are conducting experiments to establish the beneficial effects of direct solar flux in materials processing. Successful experiments have been conducted indicating that high flux processing results in enhanced properties of carbon fibers and ceramic powders.

- University of Dayton researchers have collected data from a series of experiments which will allow confirmation of the model they have developed to explain the direct-flux enhancement of efficiency in the destruction of hazardous waste. The data will provide the basis for an assessment of the technical and economic potential of solar detoxification of hazardous wastes.

- Researchers at the University of Houston (UH) have developed techniques for separating photochemical reaction enhancements which result when the reaction mass is illuminated by an intense beam of light. These techniques have shown that significant photochemical enhancement occurs for heterogeneous catalytic chemical reactions. For example, increases (up to 50,000 times) in the rate of decomposition of propyl alcohol have been observed when the irradiation is directly on the surface of the catalyst.

- Researchers at the University of Hawaii have developed a new thermal analysis technique in the course of their work on the control of solid phase reaction pathways by manipulation of the rate of heating of reaction mass.

Task 6. Transport and Storage

The primary objective of the transport and storage task is to develop high-efficiency, low-cost systems that can provide an effective match between the fluctuating solar energy resource and the thermal or electrical demand. The main emphasis of energy transport research is to identify and develop effective and economically attractive systems for transporting thermal energy from the point of collection to a storage subsystem and/or the point of use. Efficient, high-temperature storage will allow economical increases in the electrical generation capacity factor and allow solar systems to provide energy at the time of day it is most valuable.

Central Receiver Transport and Storage Technology Status

Analysis and test data indicate that the steam/oil-rock/steam[+] transport and storage system (similar to that designed for Solar One) has limited capacity at reduced temperatures and is not cost effective. Analysis indicates that sodium storage is not cost effective beyond three hours of storage (40% capacity factor). A sodium/nitrate salt/steam subsystem would have to be developed if capacity factors over 40% are required. However, analysis indicates high thermal storage potential for nitrate salt/nitrate salt/steam systems. Work under the Molten Salt Pumps and Valves project has supported the potential use of either salt-in-tube or direct absorption nitrate salt receivers. Valve packing evaluations were completed in FY1987 and a combination of commercially available packings has been demonstrated to work in 290°C salt.

An approach has been evaluated in FY1987 to reduce the operational difficulties associated with using 60% sodium nitrate and 40% potassium nitrate salt mixture that melts at 220°C to 230°C. The melting point of the 60/40 salt can be reduced to below normal ambient temperature by dissolution in water. This development has potential for greatly reducing heat trace requirements for nitrate salt systems.

Technology status highlights:

- A 0.5 MWe sodium/sodium/steam+ subsystem has been evaluated at the IEA-SSPS Project at Almeria, Spain.
- A 5 MWt nitrate salt/nitrate salt/steam+ subsystem has been evaluated at the CRTF as part of the MSEE. Under the Molten Salt Subsystem/Component (Category B) Test Experiment Project, cold and hot loops have been installed for testing pumps and valves. The purpose of this experiment is to resolve technical uncertainties associated with pumps and valves in molten salt transport/storage systems.

Distributed Receiver Transport and Storage Technology Status

The tradeoffs between central engine systems and dish-mounted engine modules linked together in a single system has long been a subject of debate in the distributed receiver systems R&D community. Central engine systems take advantage of economies of scale associated with a large engine and allow for thermal storage to better match solar availability with energy demand. However, the expense and potential losses associated with the large piping transport network for a central engine system is undesirable. A performance/economic analysis comparing sensible and thermochemical energy transport for a field of dish collectors suggests that for high-temperature applications, dishes could benefit from the success of the thermochemical transport approach. However, the development of the dish-Stirling concept, especially in systems using the variable swashplate or free-piston Stirling technologies, suggests that the dish-mounted engine approach may have cost/performance advantages over central engine systems using either sensible or thermochemical transport. Dish-mounted systems eliminate the costly thermal transport and storage network and transport their energy either directly as electricity or through a hydraulic output. In the future, work on the thermochemical transport concept will be limited while more emphasis is placed on the development of dish-Stirling systems.

[+] Receiver fluid/storage fluid/turbine fluid.

Technology status highlights:

- A transport and storage subsystem using Syltherm as the heat transfer fluid is being operated at the Solar Total Energy Project, Shenandoah, Georgia.
- An analytical assessment of thermochemical versus sensible heat transport has indicated minor potential for high-temperature applications of thermochemical transport.
- The Closed Loop Efficiency Analysis (CLEA) facility has been upgraded to achieve better selectivity in the reforming reaction, higher conversion in both the reformer and methanator, and higher overall efficiencies. The upgraded high-temperature reformer is capable of operating at temperatures from 800°C to 1000°C.
- Recent studies show that dish-Stirling systems have greater potential than dish central engine systems and are therefore the major R&D thrust.

3. Systems and Applications Technology Status

The principal research and development tasks for the Systems and Applications Technology area are (a) the assessment of innovative concepts and applications; (b) the adaptation of conventional balance-of-plant components to the solar environment; (c) the analysis, design, and experimental testing of central and distributed receiver systems; and (d) evaluations of complete systems at user sites.

Task 7. Innovative Concepts and Applications/Small Business Innovation Research (SBIR)

The objective of innovative concepts and applications research is to identify and foster the most promising novel approaches to, and applications of, solar thermal collection and conversion technology. This task provides an entry point into the mainstream of solar thermal research for promising but untried concepts and applications. Public solicitations invite and support the participation of private industry, university researchers, and the solar thermal community to recommend promising concepts and applications for the Program. Following the exploratory research phase, those concepts showing the most promise may be funded for further development.

At the present time, two innovative concepts are being evaluated under this task. Activities at the University of Chicago have involved the evaluation of an optical concept to achieve very high solar flux concentration by using a secondary concentrator. Evaluation of the use of composite materials for stretched membranes has been conducted at the University of California, Berkeley, to assess the future direction of the work which will lead to a better understanding of the behavioral characteristics of composite materials in concentrator applications.

The Small Business Innovation Research (SBIR) program is supported by DOE to encourage high-quality research or R&D proposals on advanced concepts concerning important energy-related scientific or engineering problems and opportunities that could lead to significant public benefit if the research is successful. The objectives of this program include stimulating technological innovation in the private sector, strengthening the role of small business in meeting Federal R&D needs, increasing the commercial application of DOE-supported research results and improving the return on investment from Federally funded research for economic and social benefits to the nation.

Task 8. Balance of Plant

Designing and selecting balance of plant components that are reliable under extreme thermal cycling is critical to solar thermal systems because of the cyclic nature of the solar resource. In addition, because of the variability of insolation with time of day, season, and weather condition, fully reliable automatic controls are required to reduce operating cost and maximize power production. Better methods for reducing maintenance costs of solar components, particularly concentrators and receivers, are needed. For example, present techniques of rain or manual washing of heliostats are not sufficient to ensure maximum performance. System parasitics are also too high, especially in central receiver systems, due in part to the experimental nature of the technology and the lack of sufficient design emphasis to reduce these losses.

Technology status highlights:

- Central receiver O&M experience to guide future R&D is being evaluated at Solar One in Daggett, California and the CRTF in Albuquerque, New Mexico.

- Controls and O&M data have been evaluated at the Shenandoah Solar Total Energy Project in Shenandoah, Georgia and LaJet's Solarplant 1 in Warner Springs, California.

- An assessment study of current state-of-the-art control system hardware and strategies was completed. This report evaluated the requirements for solar thermal control systems. Efforts are underway to develop the analytical tools that will aid in the proper selection of control hardware and operating procedures.

Task 9. Central Receiver Systems

Central receiver systems research and development activities include the development of designs, the analysis of system parameters, and the experimental testing of component groups and systems. The integration of components and subsystems into a complete system is necessary to properly analyze the cost and performance tradeoffs, as well as to identify critical technology development requirements. The experimental testing of groups of components furnishes valuable data on subsystem interfaces and performance in the solar environment.

The goal of the central receiver systems effort is to establish the economic feasibility of solar systems which produce electricity or industrial process heat. Current central receiver system designs for electricity generation have an annual efficiency of about 15% and a capital cost of about $3000/kWe for first plants. Current system designs for industrial process heat production have an annual efficiency of about 48% and a capital cost of about $800/kWt (peak). Long-term objectives for electricity generation are an efficiency of 18% and a cost of $1200/kWe, while for heat production, the objectives are an efficiency of 56% and a capital cost of $270/kWt(peak). Results from three high-temperature receivers have indicated that because of advances in central engines, the high temperature systems have the potential to meet long-term systems cost goals.

Technology status highlights:

- Completion of the two-year test and evaluation phase and the three-year power production phase at the Solar One 10 MWe Pilot Plant has demonstrated the feasibility of central receiver technology. Solar One will continue to operate in a semi-commercial phase (5 days a week) through July 1988. Funding for the semi-commercial phase will be provided by DOE and EPRI.

- The MSEE experiment at the CRTF has completed all test phases, and the Molten Salt Subsystem/Component (Category B) Test Experiment Project has been installed and testing initiated.

- Testing and evaluation of the IEA Small Solar Power System (SSPS) Central Receiver Project in Almeria, Spain has been completed. The SSPS utilized sodium as the working fluid and was capable of generating 500 kWe.

- A group of western utilities are studying an appropriate path to the next generation of central receiver technologies in utility applications. Phase I of the utilities study has been completed with the conceptual design of the preferred configuration for the solar power tower. The results verify the ability to attain DOE mid-term cost goals for molten salt central receiver plants.

- An updated central receiver handbook has been developed to assist in the design of central receiver systems in the range of 15-200 MWe.

- Alternative conceptual configurations and flow patterns have been assessed for DARs, and reveal designers will have considerable flexibility in choosing design parameters.

Task 10. Distributed Receiver Systems

The objective of the distributed receiver systems task is to develop systems that collect thermal energy for the production of heat and electricity at costs that are competitive with the projected costs for conventional energy forms. Research in distributed receiver systems includes concept definition, application analysis, integration of component characteristics, specification of new component requirements, and system-level experimental testing to obtain data to verify theoretical models.

Two basic types of parabolic dish/electricity systems are gaining prominence: (a) modular units with electricity generated by a heat engine at the focus of the dish, and (b) designs where heat is absorbed by a transfer fluid passing through a small receiver at the dish focal point and then transported to a central turbine-generator. The former approach requires a more costly heat engine but very little transport cost, while the latter approach utilizes a relatively inexpensive receiver and standard steam-Rankine turbine, but a more costly (sensible heat or thermochemical) transport system.

The distributed receiver systems efforts are directed toward maximum utilization of R&D under the central receiver activities, such as silver reflectors, stretched membranes, absorber coatings, reflector washing, controls, test facilities, etc.

Technology status highlights:

- Cogeneration capability (electricity, process steam, and absorption cooling) has been demonstrated at the Solar Total Energy Project, Shenandoah, Georgia. The third year of utility ownership and operation has been completed. The operating utility, Georgia Power Company, has performed and will continue to perform several modifications to the system to upgrade performance.

- A video fluxmapper, a tool for characterizing the flux field produced by a point-focus concentrator, has been installed at the Distributed Receiver Test Facility (DRTF) and operation has begun.

- A record conversion efficiency for sunlight to electricity (31% gross, 29% net) has been achieved with the Vanguard dish/Stirling engine experiment at Rancho Mirage, California.

- Using private funding and tax credits, LaJet Energy Company constructed a 4.9 MWe commercial system at Warner Springs, California. The system was constructed using 700 of LaJet's low-cost, 7.4-meter diameter multi-faceted parabolic concentrators. The system has been operating successfully for the past three years and is currently undergoing a retrofit to convert the system to a solar-diesel combined cycle.*

---

*Non DOE Solar Thermal Technology funding.

- **Luz Industries constructed two parabolic trough electric systems (SEGS I and II) totalling nearly 44 MWe at the Southern California Edison (SCE) site at Daggett, California. These units have been on-line for several years. SEGS III through V, each with rated capacity of 30 MWe, have been constructed nearby at Kramer Junction, California. SEGS III and IV came on-line during December 1986, and SEGS V is expected to come on-line during December 1987. Luz has also signed an agreement with SCE to deliver power from SEGS VI-XIX (30 MWe each) as these are installed over the next several years.***

Task 11. System Experiments

Solar thermal system experiments provide needed data on capital cost, performance, and operation and maintenance. System experiments are conducted with major participation from solar equipment manufacturers and potential users. These experiments lead to the establishment of technical feasibility, the development of a cost and performance data base, technology transfer that can be used in private sector decisions, and the identification of future research and development needs.

Several major system experiments are now on-line. Operations and maintenance data are being evaluated from the Solar One 10 MWe Solar Central Receiver Pilot Plant near Barstow, California; the 3 MWt parabolic dish total energy (cogeneration) plant at Shenandoah, Georgia; the LaJet 4.9 MWe parabolic dish facility near Warner Springs, California*; and the large Luz parabolic trough electricity generation plants at Daggett and Kramer Junction, California.* Daily operations at the Barstow central receiver experiment and at the Shenandoah parabolic dish facility are now the responsibility of their respective utility users, Southern California Edison and Georgia Power. In addition, two experiments using parabolic dish technology are being conducted to evaluate solar electric plants in a small community/utility environment, one to be located at Osage City, Kansas (SCSE #1), and the other at Molokai, Hawaii (SCSE #2). To establish system feasibility and to identify the operations and maintenance costs of these experiments, several years of operating experience will be accumulated for all the plants' operating modes. The plants' system and component performance will also be evaluated.

C. Fiscal Year 1987 Program Accomplishments

A summary of the Fiscal Year 1987 major accomplishments of the Solar Thermal Technology Program is presented below for the areas of Collection Technology, Conversion Technology, Systems and Applications Technology, and Planning and Assessment.

1. Collection Technology Accomplishments

- Continued outdoor weathering tests at several sites demonstrated that silvered polymers can have excellent initial optical properties when used with mirrors in a stretched membrane configuration or mounted on stiff substrates. ECP 300 or glass substrate maintained performance levels of reflectance of greater than 90% at 4 mrad after 89 weeks at Golden, Colorado and greater than 90% at 8.4 mrad after 15 months at Arizona and Florida. ECP 300X shows no silver corrosion after 3.4 years outdoors in Golden. These results are approaching the long-term program goal to obtain a mirror having a reflectance of at least 90% at 2 mrad with a 5 year lifetime.

- Benzotriazole - type UV absorbers were selected as the primary stabilizer system for protection of mirror surfaces and backings. The system will undergo further research and evaluation at SERI.

---

*Non DOE Solar Thermal Technology funding.

- Small scale experiments using the DAR Inconel test loops were conducted at SERI to understand the nitrate salt film behavior with and without a dopant using simulated solar flux.

- Both Innovative Parabolic Dish Concentrator prototypes have been completed and installed at the DRTF for testing.

- Detailed designs of two $150m^2$ stressed membrane heliostats were completed during FY1986. Both $55m^2$ prototypes have been installed and tested at the CRTF. Contracts are in place for further development and include the fabrication of two improved prototypes.

- A 20kW thermochemical receiver/reformer built by Sandia began testing at the Weizmann Institute of Science in Israel as part of a United States-Israel bilateral agreement.

- Experiments were conducted to assess the behavior of nitrate salt films for use with Direct Absorption Receiver (DAR) systems.

- Installation of a 5 MWt subscale molten salt cavity receiver (configured like manufactured article) for testing at the CRTF has been completed, and operation initiated.

- Installation of a large area ($200m^2$) glass metal heliostat at the CRTF has been completed and testing initiated. Both the $150m^2$ and $200m^2$ units will continue testing during FY1988.

- Contracts have been awarded to Solar Kinetics, Inc. and LaJet Energy Company to develop stretched membrane dishes. Phase I design reviews were conducted during FY1987.

2. Conversion Technology Accomplishments

- Research continued on free-piston Stirling engines under cooperative agreement with NASA/Lewis Research Center. Preliminary and final concept designs were reviewed.

- SERI completed a two-year research plan for the Regenerative Thermoelectrochemical Converter (RTEC). Work will be performed under a cost-shared agreement with Hughes Aircraft. In addition, SERI initiated development of a computer model to characterize a dish-RTEC system.

- A cost-to-manufacture study of the MTI and STC free-piston Stirling engine designs has been conducted by Pioneer Engineering. The preliminary results indicate that the systems proposed by MTI and STC are capable of meeting the DOE long-term goals when manufactured in quantities greater than 10,000 units per year.

- Stirling Thermal Motors (STM) has designed a solarized version of the STM4-120 kinematic Stirling with variable swashplate. A new design with 4 gas-fired heat pipes has been demonstrated at STM's facility with encouraging results. Full power testing on-sun is scheduled at DRTF during FY88.

- The University of Houston has developed techniques for separating photochemical reaction enhancements. These techniques have been used to show that significant photochemical enhancement occurs for heterogeneous catalytic chemical reaction.

- The University of Dayton investigated solar enhancement of photolytic and rapid heating reactions for use in the detoxification of hazardous wastes as well as to obtain a better understanding of the basic phenomena.

- Georgia Tech Research Institute has conducted 27 experiments on solar processing carbon fibers under various conditions. Results indicate that the degree of graphitization of selected carbon fibers has increased by the use of solar processing.

- The Closed Loop Efficiency Analysis (CLEA) facility was upgraded to accommodate higher reformer temperatures and increased methanation capacity, thus allowing for better selectivity in the reforming reaction, higher conversion in both the reformer and methanator, and higher overall efficiencies.

- Coking experiment to investigate carbon formation in the presence of catalysts has been completed. This included the thermogravimetric investigation of the initiation of coking in the CO_2/CH_4 reforming/methanation cycle as a function of temperature, gas composition, and catalyst.

- A contract was placed in early FY1987 with Resource Analysis International (RAI), Inc. to perform a detailed design of the Closed Loop Operations Experiment (CLOE) Phase I system. A decision was made to scale-down the design. The design will be less complex to operate and will still meet almost all of the original goals of the experiment.

3. Systems and Applications Technology Accomplishments

- The University of California, Berkeley, completed the first year of their three-year effort to evaluate the use of composite materials for stretched membranes.

- The University of Chicago finished the first year of their multi-year effort to evaluate optical concepts to achieve high solar flux through the use of secondary concentrators.

- Sandia completed development of dynamic simulation computer models for both a salt-in-tube and a Direct Absorption Receiver, and initiated validation of the salt-in-tube model.

- System studies were undertaken to enhance the state of theoretical and experimental knowledge of the DAR, which led to the selection of a configuration for a commercial-scale receiver.

- The Phase I conceptual designs for the Central Receiver Utility studies have been completed. Initial designs are for 100 MWe plants (with eventual scale-up to 200 MWe) utilizing molten salt external receivers and stressed membrane heliostats.

- During FY87, Georgia Power Company (the operating utility company) completed a number of modifications to the Shenandoah Solar Total Energy Project (STEP), to expand and improve performance.*

- Participation in the Small Community Solar Experiments Cooperative Agreements continued. The SCSE #1 (Osage City, Kansas) parabolic dish module is being tested at the DRTF. Installation of the SCSE #2 (Molokai, Hawaii) module at the DRTF for testing was initiated.

- Phase II of the Central Engine Study, which examined central engine availability concepts in the 500 kW to 50 MW size range with operating temperatures between 400^oC and 500^oC has been completed.

- Development of a Shenandoah Total Energy Project (STEP) test program to provide baseline commercial operations information has been initiated. The program is approximately 50% complete.

- Participation in the Solar One 10 MWe Solar Thermal Pilot Plant Cooperative Agreement continued. The three-year utility power production phase has been completed.

---

*Non DOE Solar Thermal Technology funding.

- Installation of the Molten Salt Subsystem/Component Test Experiment (Category B) at the Central Receiver Test Facility (CRTF) has been completed, and operation initiated. The project is designed to resolve technical uncertainties which relate to the critical components of a molten salt central receiver plant: pumps, valves, and the receiver.

- Luz Industries completed construction of SEGS III and IV, and neared completion of SEGS V. All three plants have an output of 30 MWe, and are located at Kramer Junction, California. These additions bring the total output of the SEGS plants (SEGS I-V) to over 130 MWe.*

- LaJet Energy Company's Solarplant 1 completed another year of successful operation. The 4.9 MWe plant contains 700 of LaJet's low-cost 7.4 m diameter concentrators, and delivers energy to the San Diego Gas and Electric grid.*

4. Planning and Assessment Accomplishments

- The Solar Thermal Research Annual Conference was conducted at Golden, Colorado on February 18-20, 1987.

- The Solar Thermal Central Receiver and Distributed Receiver Annual Conference was conducted at Albuquerque, New Mexico on August 26-27, 1987.

---

*Non DOE Solar Thermal Technology funding.

III. FISCAL YEAR 1988 PROGRAM STRUCTURE

A. FY1988 Solar Thermal Technology Program

Fiscal Year 1988 Solar Thermal Technology Program activities managed by the laboratory and field organizations have been grouped into the following categories:

- Collection Technology
- Conversion Technology
- Systems and Applications Technology
- Planning and Assessment

Table 1 shows the existing FY1988 program structure, indicating major program elements and responsible organizations.

B. FY1988 Program Resources and Major Milestones

The solar thermal technology FY1988 budget is shown in Table 2. Major solar thermal technology FY1988 milestones are summarized in Figure 4.

C. FY1988 Program Task Descriptions

Significant progress has been made in the development of solar thermal technology since the inception of the DOE program. Solar thermal central receivers, dishes, and troughs have all been successfully built and tested. In order to meet current and projected market requirements, however, further development of these concepts is needed. Much of this effort will concentrate on high risk, long-term payoff R&D appropriately conducted by the Federal government with participation and cooperation from industry. The DOE Solar Thermal Technology Program for FY1988 is designed to conduct this research based on a balanced, comprehensive plan which has been established by comparing the current development status of the technologies with system-level performance targets. This comparison provides the basis for identifying and assessing the magnitude of the remaining technical and economic barriers to widespread use of solar thermal technologies.

The Solar Thermal Technology Program is structured into 11 major R&D task areas, each with research activities specifically directed toward achieving the program goals and planning targets. The research activities to be conducted in FY1988 for each of the task areas are described below.

1. Collection Technology

Task 1. Optical Materials

FY1988 optical materials research, managed principally by SERI with assistance from Sandia, is structured into the following subtasks:

Table 1. THE SOLAR THERMAL TECHNOLOGY PROGRAM STRUCTURE

SOLAR THERMAL TECHNOLOGIES		
COLLECTION TECHNOLOGY	CONVERSION TECHNOLOGY	SYSTEMS & APPLICATIONS TECHNOLOGY
1. Optical Materials ● Silver Ultralight Polymer Reflectors (SUPR) (SERI) ● Structural Membrane Composite Materials Research (SERI) ● Soiling and Cleaning of Solar Reflectors (SERI) ● Thin Foil Stainless Steel Reflectors (Sandia) 2. Concentrators ● Central Receiver Concentrator R&D (Sandia) ● Distributed Receiver Concentrator R&D (Sandia) ● Advanced Concentrator Research (SERI) 3. Receivers ● Central Receiver R&D (Sandia) ● Distributed Receiver R&D (Sandia) ● Advanced Receiver Research (SERI)	4. Heat Engines ● Stirling Engine Cycles (Sandia) ● Regenerative Thermoelectrochemical Conversion (RTEC) Heat Engine Research (SERI) ● Heat Engine Analysis (Sandia) 5. Direct Conversion (SERI) ● Direct Conversion of Solar Thermal Energy ● Solar Induced Surface Transformations of Materials 6. Transport & Storage (Sandia) ● Molten Salt Pump & Valve ● Advanced Salt Transport Fluids	7. Innovative Concepts & Applications/ Small Business Innovation Research (SERI) ● New Ideas/Innovative Concept Development at Universities ● Small Business Innovation Research 8. Balance of Plant (Sandia) ● Automated Control Systems 9. Central Receiver (CR) Systems (Sandia) ● Systems Applications Studies ● CR Test Facility 10. Distributed Receiver (DR) Systems (Sandia) ● Systems Engineering, Evaluation & Analysis ● DR Test Facility 11. System Experiments (Sandia) ● Solar One-10MWe Barstow Project ● Small Community Solar Experiments

Table 2
SOLAR THERMAL TECHNOLOGY
FY 1988 BUDGET
(Dollars in Thousands)

PROGRAM ELEMENT	FUNDING ORGANIZATION						
	HQ	SAN	ALO	SERI	SANDIA		TOTAL
					DR	CR	
● COLLECTION TECHNOLOGY							
1. Optical Materials	--	--		1,240	300	--	1,540
2. Concentrators	--	--		1,000	1,710	1,680	4,390
3. Receivers	--	--		1,200	950	1,880	4,030
							9,960
● CONVERSION TECHNOLOGY							
4. Heat Engines	--	--		270	1,250	--	1,520
5. Direct Conversion	--	--		800	--	--	800
6. Transport & Storage	--	--		--	--	200	200
							2,520
● SYSTEMS & APPLICATIONS TECHNOLOGY							
7. Innovative Concepts	210 *	--		150	--	--	360
8. Balance of Plant	--	--		--	--	--	0
9. CR Systems	--	--		--	--	1,790	1,790
10. DR Systems	--	--		--	970	--	970
11. Systems Experiments	--	250 **		--	200	100 **	550
							3,670
● PLANNING & ASSESSMENT	400	--		400	--	--	800
● CAPITAL EQUIPMENT	--	--		44	22	22	88
TOTAL	610	250		5,104	5,402	5,672	17,038

* SBIR

** $350,000 is provided to maintain the operations of Solar One per the House Appropriation Mark.

Figure 4.
SOLAR THERMAL TECHNOLOGY
FISCAL YEAR 1988 MAJOR MILESTONES

TASK	FISCAL YEAR 1988											
	1ST QTR			2ND QTR			3RD QTR			4TH QTR		
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
COLLECTION TECHNOLOGY												
• Optical Materials						1						2
• Concentrators		3				4	5		6 7 8	9 10		
• Receivers				11					12 13	14		15
CONVERSION TECHNOLOGY												
• Heat Engines						16 17	18	19				
• Direct Conversion							20					21 22
• Transport and Storage												23
SYSTEMS & APPLICATIONS TECH.												
• Innovative Concepts												24
• Balance of Plant						25						
• Central Receiver Systems			26									
• Distributed Receiver Systems							27					
• Systems Experiments								28	29			30
PLANNING AND ASSESSMENT									31			

1. CONDUCT EXPERIMENTAL VERIFICATION OF ABSORPTION AS A FUNCTION OF DOPANT CONCENTRATION IN SALT – SERI
2. FABRICATE SETS OF CANDIDATE MATERIALS USING MOST PROMISING COMBINATION OF COATINGS AND SUBSTRATE FOR SITE EVALUATION – SERI
3. COMPLETE DETAILED DESIGN REVIEW OF STRETCHED MEMBRANE DISH DESIGNS – DR
4. PLACE STRETCHED MEMBRANE DISH PHASE II CONTRACT – DR
5. QUANTIFY WIND LOADS ON DISH STRUCTURES AND DEFINE PREFERRED CONFIGURATIONS FOR REDUCING WIND LOADS – SERI
6. COMPLETE FIRST GENERATION STRESSED-MEMBRANE HELIOSTAT EVALUATION PROGRAM – CR
7. COMPLETE LARGE-AREA HELIOSTAT EVALUATION PROGRAM – CR
8. COMPLETE DRTF TESTS OF LaJET INNOVATIVE CONCENTRATOR – DR
9. INITIATE SECOND GENERATION STRESSED-MEMBRANE HELIOSTAT PROTOTYPE(S) EVALUATION PROGRAM – CR
10. FABRICATION OF 3-METER PROTOTYPE COMPOSITE MEMBRANE DISH – SERI
11. COMPLETE DOPED-SALT, HIGH FLUX PANEL TEST – SERI
12. COMPLETE DIRECT ABSORPTION RECEIVER (DAR) WATER FLOW EXPERIMENT – CR
13. COMPLETE LONG SALT-FILM WAVE STABILITY EXPERIMENT WITHOUT FLUX – SERI
14. COMPLETE FABRICATION OF REFLUX RECEIVER FOR KINEMATIC STIRLING ENGINE – DR
15. COMPLETE DIRECT ABSORPTION RECEIVER (DAR) SALT LOOP CONSTRUCTION AND BEGIN TESTING – CR
16. DELIVER STIRLING THERMAL MOTORS KINEMATIC STIRLING ENGINE TO DRTF – DR
17. DEFINE CONCEPTUAL CONFIGURATION OF REGENERATIVE THERMO-ELECTRICAL CONVERTOR (RTEC) FOR DISH APPLICATION – SERI
18. COMPLETE EXPERIMENTAL CHARACTERIZATION OF EQUILIBRIUM REGENERATION OF RTEC WORKING FLUID IN THE REGENERATOR – SERI
19. PLACE FREE-PISTON STIRLING ENGINE PHASE II CONTRACT – DR
20. ANALYZE COATINGS EXPOSED TO SOLAR FLUX AND PICK THE MOST PROMISING MATERIALS TREATMENT APPLICATIONS – SERI
21. TEST SOLAR DETOXIFICATION REACTOR WITH CONCENTRATED FLUX – SERI
22. VERIFY THROUGH EXPERIMENTS THE BENEFICIAL EFFECTS OF CONCENTRATED SUNLIGHT ON AT LEAST ONE CHEMICAL REACTION SHOWING HIGH INDUSTRIAL VALUE – SERI
23. COMPLETE FULL-SCALE PUMP & VALVE EXPERIMENT (FIRST GENERATION) – CR
24. REVIEW PROGRESS OF HIGHLY CONCENTRATING SOLAR FLUX RESEARCH AND ASSESS OPPORTUNITIES FOR FUTURE DEVELOPMENT – SERI
25. INSTALL CONTROL SYSTEM FOR KINEMATIC STIRLING ENGINE – DR
26. EVALUATE POTENTIAL SYSTEM IMPACT OF SUBSTRATE REFLECTOR FILM STACK SPECULAR REFLECTANCE – SERI
27. COMPLETE DISH-ELECTRIC PRELIMINARY STUDY – DR
28. COMPLETE DRTF TESTS OF SECOND SMALL COMMUNITY SOLAR EXPERIMENT (SCSE2) MODULE – DR
29. COMPLETE DRTF TESTS OF FIRST SMALL COMMUNITY SOLAR EXPERIMENT (SCSE1) MODULE – DR
30. COMPLETE FIRST YEAR SOLAR ONE SEMI-COMMERCIAL OPERATION – CR
31. CONDUCT FOURTH INTERNATIONAL SYMPOSIUM ON RESEARCH, DEVELOPMENT AND APPLICATIONS OF SOLAR THERMAL TECHNOLOGY

- **Silver Ultralight Polymer Reflectors (SUPR)**
- **Structural Membrane Composite Materials Research**
- **Soiling and Cleaning of Solar Reflectors**
- **Thin Foil Stainless Steel Reflectors.**

Silver Ultralight Polymer Reflectors (SUPR)

The objective of this research is to obtain silver/polymer reflecting surfaces that meet long-term durability goals, while maintaining high-specularity performance, and which operate satisfactorily in the solar environment. Silver/polymer materials which are being developed for membrane concentrators have the potential for significantly reducing the cost (by more than 50%) and weight (by more than 75%) of heliostats and dishes. The long-range goals, as defined by system analysis, are to obtain a mirror capable of maintaining a reflectance of at least 90% for solar radiation (300-2600 nanometers) into a half-cone acceptance angle of 2 milliradians. The mirror should also be capable of maintaining this optical performance for at least 5 years. SERI researchers have already shown that silvered polymers can have excellent initial optical properties which exceed these long-range goals. Accelerated and real-time testing in relatively benign environments show that silver in these membranes can be protected from corrosion for at least 3 years and full optical performance can be maintained for at least 1-1/2 years. However, performance at sites in harsher environments degrades more rapidly. Reflector performance is also subject to significant degradation because of reversible surface soil. Experience at the Sandia test site has shown that specular reflectance losses of silver/glass mirrors are from 0.5 to 1.0% per day, with losses approaching 20% in 2 years.

Research activities during the current fiscal year will continue UV stabilizer development with emphasis on solving the degradation problems observed in harsh environments, and investigation of surface chemistry alteration directed to anti-soiling. Specific activities during FY1988 will include:

- Improvement of the UV stabilizer system aiming for the 5-year life goal in a harsh environment, such as Arizona, and continuation of testing of the primary stabilizer system and its modification for compatibility with surface treatments for soiling and abrasion resistance.
- Identification of surface treatments for abrasion-resistant hard coats capable of protecting the polymer and binding soil less rigidly. Fluorinated surfaces are known to have decreased surface energy and can be adapted to intrinsically hard surfaces, so fluorination will be a first approach.

Structural Membrane Composite Materials Research

The objective of this research is to evaluate the material, structural and fabrication issues associated with various composite membrane and structural support element concepts for both dish and heliostat applications. The major advantages of using composite materials in membrane and structural applications are (1) their inherent durability and ease of fabrication, (2) their initial cost reduction potential, and (3) the potential for weight reduction. Composite membranes could also eliminate welds on the membrane and associated optical distortions and they appear to be amenable to preforming into the desired shape (i.e., for dish applications) without the need for plastic deformation.

This subtask will investigate the materials and mechanics issues associated with component structural stretched membrane reflector substrates as well as refining anticipated likely major cost/performance advantages and limitations of various promising composite material candidates. Research activities planned for FY1988 include:

- Investigation of the required modifications to matrix materials with glass reinforcements to improve surface quality and the structural micromechanics issues and requirements for component membrane structures.

Soiling and Cleaning of Solar Reflectors

The objective of this research is to develop methods for minimizing the efficiency losses of large area heliostats and dish concentrators due to soiling. Prior work indicates that short-term reflectance losses of silver/glass mirrors are from 0.5% to 1.0% per day at the Sandia (Albuquerque) site with losses approaching asymptotic values of about 20% in 2 years. The loss of power at the central receiver is roughly twice that of the loss in reflectance of the heliostats; therefore, eliminating soil from reflecting elements is a necessary condition for optimum performance of such a system.

The goal of FY1988 research is to gain an understanding of the loss of reflectance upon soil accumulation as samples are exposed to real-time field conditions, the effects of various cleaning methods, and to relate these observations to the experimentation in the laboratory. The specific activities planned are:

- Exposure of samples of ECP 300, modified PMMA, silver/glass, and other novel reflector materials to laboratory soiling and cleaning procedures in a cyclic manner.
- Measurement of the specular reflectance (or transmittance) at each step of the soiling and cleaning cycles to determine the effects of exposure.
- Surface analysis on residual layers which build up on the surfaces of the reflectors.
- Comparison of these data to similar data derived from real-time exposure at field sites (Golden, Brighton, Albuquerque, Barstow).
- Monitoring the subcontract with Industrial Solar Technology to develop soiling and cleaning history of an operating concentrator system using ECP 300.
- Working on optimization of anti-fouling coating for silver/polymer materials (SERI, GTRI).

Thin Foil Stainless Steel Reflectors

An alternative to silver/polymer membranes for lightweight, low-cost reflectors, is the stainless steel structural mirror. The steel mirror has the advantage that it can be self supporting and can also withstand the loads imposed by wind and gravity. Over the past 2 years, Sandia has pioneered the development of the sol-gel process for protecting thin foil steel membranes while maintaining high specular reflectance. The sol-gel process has made it possible to develop a high quality silver-on-stainless mirror by acting as a dielectric insulator that can prevent galvanic corrosion.

In FY1988, Sandia will continue thin foil stainless steel reflector development with specific activities to include:

- Optimization of the sol-gel mirror process.
- Transfer of the sol-gel technology to an industrial contractor in order to assure the DOE program a supplier of reflective material in moderate quantity in support of R&D activities and to provide a source for near-term commercial applications.

Task 2. Concentrators

Concentrators are the most expensive part of any solar thermal system and their performance has a direct impact on overall system cost and efficiency. The objective of this task is to develop high performance, low-cost concentrators for thermal processes and electrical power generation. Research and development activities are intended to achieve cost reductions with little or no performance degradation. FY1988 concentrator research is structured into the following subtasks:

- Central Receiver Concentrator R&D
- Distributed Receiver Concentrator R&D
- Advanced Concentrator Research.

Central Receiver Concentrator R&D

The concentrators in central receiver systems are large sun-tracking mirrors (heliostats) which concentrate the solar energy incident on the earth by redirecting it to a tower-mounted receiver. Early (first generation) heliostats cost approximately $1000/m^2. The current estimated cost of silvered-glass heliostats is $150/m^2 at moderate production rates. It is projected that mass production of heliostats could result in a cost of $80/m^2 for glass/metal reflectors. The long-term objective is $40/m^2 for stretched membrane heliostats. The overall strategy for achieving these cost goals is to continue the stepwise improvements in glass/metal technology through the development of large area glass/metal heliostats while also pursuing innovative concepts such as stretched membrane designs that have the potential for dramatic cost reductions. As costs of reflectors decline, drive mechanisms will become a more significant fraction of overall heliostat costs, and efforts are underway to develop low-cost drive mechanisms. Because heliostat performance has a direct impact on overall Central Receiver plant performance efficiency, cost effective cleaning systems will be studied for large-area glass/metal and stressed membrane heliostats. Major planned activities for central receiver concentrator R&D during FY1988 include:

- Completion of test and evaluation at the CRTF of large area (150m^2-200m^2) glass/metal heliostats developed by Advanced Thermal Systems Corp. and Solar Power Engineering Company (SPECO).
- Completion of testing of the SKI 50m^2 first generation stretched membrane prototype heliostat and initiation of testing of the second generation concepts under development by SKI and SAIC. A decision will also be made whether to continue development of both concepts after the second generation prototypes are tested and whether testing of a larger-than-50m^2 prototype or a small build of 50m^2 heliostats will be most beneficial to achieving program goals.
- Construction and testing of prototype low-cost heliostat drives designed in FY1987 under simulated gravity and wind load conditions.
- Participation in a joint SERI and Sandia program to evaluate potential heliostat cleaning methods using the large-area heliostats and stressed membrane mirror modules at the CRTF as test cases.

Distributed Receiver Concentrator R&D

The purpose of this effort is to develop high performance, low-cost solar concentrators to serve as an energy source for thermal processing and electrical power generation in distributed receiver systems. The primary emphasis of R&D is in development of alternative concepts for point-focus concentrators including large facet stretched membrane concepts. In addition, effects of wind-induced loads on dish receivers are being evaluated. Research activities planned for FY1988 include:

- Testing and evaluation of the LaJet Innovative Point Focus Concentrator prototype at the DRTF.

- Continuation of Phase II detailed design of the Stretched Membrane Dish Concentrator Development Project (large facet). Under this project, two prototype designs are being developed. The SKI design is an annular ring fixed to an axial post with tensioned cables and to which an aluminum front membrane (fabricated using a free-form yielding approach) and a back membrane are attached. The LaJet design utilizes a fiberglass/vinylester resin/PET/ECP 300 membrane which is preformed on a tool plaster mandrel.

- Instrumentation installation on critical locations of several collectors at the DRTF so that actual wind-induced loads and moments can be measured and analyzed.

Advanced Concentrator Research

This research will develop an in-depth understanding of the major technical issues concerning advanced concentrators, including the structural and optical performance of next generation dish modules and secondary concentrators. Research will also continue on wind loadings on concentrators and their implications for system design. The following research activities will be performed during FY1988:

- Continuation of work with SAIC and the University of California to evaluate viable composite concentrator membrane options.

- Evaluation of the structural response, optical performance, and thermal efficiency characteristics of various membrane/frame/support structure configurations using a variety of finite element analysis, optics, and thermal performance codes. Results of this work will lead to determination of membrane and frame design requirements to obtain optimum performance at minimum weight.

- Continuation of wind load studies and research into the wind load characteristics of dish modules and fields and development of a revised wind load specification and design guideline for dishes.

Task 3. Receivers

The receiver is a key component of both central and distributed receiver solar thermal systems. Its design must meet the requirements imposed by the concentrator(s) and the power conversion or thermal process subsystem. Receiver R&D is aimed at improving efficiencies, reducing costs, and improving structural and thermal receiver designs. For FY1988, receiver research is structured into the following subtasks:

- Central Receiver R&D

- Distributed Receiver R&D

- Advanced Receiver Research.

Central Receiver R&D

The principal focus of central receiver research is finding the best cost/performance subsystems and systems for applications up to 600°C. The receivers operating in this temperature range will enable electricity production through coupling with the common Rankine-cycle steam turbine or use in intermediate temperature industrial processes. Emphasis will be on improving the reliability and decreasing the fabrication cost of molten salt receiver configurations which have been developed during the past several years. In addition, engineering development of a molten salt direct absorption receiver has begun as this promising technology moves from the research stage into the development stage. The program will also be involved, primarily through participation in international cooperative programs, in assessing the potential of high temperature receiver concepts (800-1000°C) which have the potential for making Central Receiver technology suitable to many new process heat, fuels and chemicals, and high-efficiency electric conversion applications. Major planned activities during FY1988 under the central receiver R&D are to:

- Decide whether to continue an extended period of "power production" performance and life testing of an advanced 5 MWt molten salt receiver under the Molten Salt Subsystem/Component (Category B) Experiment. This decision will be made as a result of recommendations from the Utility Studies.

- Contine development of the direct absorption receiver (DAR) concept through activities such as investigation of the potential for reactive carbon dopants, performance of structural and thermal analysis of conceptual commercial DAR designs, exploration of the potential of using a multi-layer wire mesh absorber substrate instead of dopants, completion of the Sandia small-scale water flow testing, and initiation of full-scale water flow testing and the 2 MWt solar test at the CRTF.

- Provide minimum support to tests of a volumetric receiver at the IEA/SSPS facilities in Spain and a ceramic tube receiver in Israel.

Distributed Receiver R&D

Since the receiver is a key component of a distributed receiver system, its design is closely tied to the specific system and application for which it is built. The reflux receiver concept is a promising option because of the manner in which it decouples the thermal load and the heat source, thus allowing for better control of solar powered heat engines and potential fossil fuel-hybrid concepts. The objective of this task is to develop analytical and experimental tools and techniques and to experiment with and evaluate advanced distributed receiver concepts. Major planned activities under this task during FY1988 are:

- Evaluation of the "pool boiler" and sintered powder wick reflux receiver configurations proposed in the free-piston Stirling engine preliminary designs. Subsequent to this evaluation a receiver will be designed, built , and ready for test in October 1988.

- Initiation of testing of the gas-solar hybrid reflux receiver for the STM4-120 Stirling engine which will be delivered to Sandia in July 1988.

- Continuation of development of receiver design computer codes along with experimental validation of these codes using newly developed devices for the measurement of flux and temperatures in a receiver.

- Investigation of general reflux concerns at the component level including long-term material compatibilities, stress analysis, wicking, and cavity designs.

- Evaluation of a catalytically enhanced solar absorption receiver (CAESAR) as part of IEA/SSPS Task 3 research on solar driven thermochemical processes.

Advanced Receiver Research

Advanced receiver research is focused on identifying and verifying the technical feasibility of new receiver concepts; obtaining fundamental data on receiver materials and mechanisms; and characterizing new components, materials, and subsystems. The direct absorption receiver (DAR) concept will continue to be investigated to address many of the remaining heat transfer and fluid dynamics issues needed for understanding the phenomena of direct absorption of concentrated solar flux in doped nitrate salt.

Other objectives of this task are to discover or develop highly effective, chemically inert, non-settling blackeners for high temperature heat transfer fluids; to discover or develop high temperature heat transfer fluids having wide liquid temperature ranges; to investigate compatibility of high temperature heat transfer fluids and containment materials used in pipes, reservoirs, valves, etc.; and to provide data on physical and chemical properties of materials used in DARs. Research activities planned for FY1988 include:

- A variety of experiments to characterize molten salt wavy film flow and stability under high flux and high Reynolds number flow conditions will be conducted.

- A large panel DAR test at the CRTF will be conducted. The test objective will be to verify previous research conducted separately on phenomena such as: the absorption of concentrated flux, film stability due to flux variations and long-film stability, and convective heat transfer coefficient experiments.

- Continuation of the search for wide melting temperature range heat transfer fluids with the constraint that these fluids must remain in the same cost realm as nitrates with some allowance for savings resulting from the elimination of trace heating.

- Continuation of development of blackeners with emphasis on the use of cryptocrystalline, transition metal oxides.

- Continuation of corrosion studies of chromium, iron, and nickel based alloys in the presence of nitrate salts at temperatures above 600°C. This work will include preliminary studies of the solubility of the protective metal oxides formed on these metals in nitrates and other possible DAR heat transfer fluids .

2. Conversion Technology

Task 4. Heat Engines

The primary heat engine R&D activities in the past few years have involved the dish-electric concept in which a heat engine and generator are located at the focus of a parabolic dish concentrator for heat-to-electric energy conversion. These activities will continue to be the main thrust of this task area and will be performed under the following subtasks:

- Stirling Engine Cycles

- Regenerative Thermoelectrochemical Conversion (RTEC) Heat Engine Research

- Heat Engine Analysis.

Stirling Engine Cycles

Stirling engine field experiments to date have concentrated on the kinematic engine. Early versions of the kinematic engine experienced serious maintenance problems associated with the high pressure control strategies required. An alternative approach to the kinematic Stirling engine is the variable swashplate design. In this approach a wobbling plate, or swashplate, is used to control the engine power output by continuously varying the piston displacement. This configuration will continue to be investigated during FY1988.

Another candidate, being developed by NASA for the space program, is the free-piston Stirling engine (FPSE). This engine has the potential for high reliability, long life, low maintenance, and high efficiencies, and is being considered for solar thermal applications. Cooperative research will continue on the FPSE with participation from NASA and Sandia. Planned activities in this subtask for FY1988 include:

- The conceptual designs of a solarized FPSE developed by Mechanical Technology Inc. (MTI) and Stirling Technology Co. (STC) will be evaluated by NASA/LeRC and Sandia and based on one design or a combination of both, a competitive contract will be awarded for a detailed design and fabrication.

- Initial testing of solarized STM4-120 engine at the DRTF using a gas-fired heater will be conducted. On-sun testing with a reflux receiver will begin as soon as possible after initial testing is completed. In addition, a second kinematic Stirling engine will be purchased from STM in mid-FY1988.

Regenerative Thermoelectrochemical Conversion (RTEC) Heat Engine Research

The objective of this research is to define a regenerative thermoelectrochemical conversion (RTEC) concept, demonstrate its technical feasibility, and assess its cost and economic potential. RTEC converters show great promise in both central and distributed receiver systems. Major benefits include 1) potential for up to 40% heat-to-electric conversion efficiency; 2) mean-time-between-failure may exceed 40,000 hours; 3) high reliability due to very few moving parts; and 4) inexpensive energy storage in the chemicals being regenerated. During FY1988, the program will conduct research on RTEC including:

- Definition of solid polymer electrolyte/electrode systems with a minimum of precious metal catalyst.

- Continued development of the thermal regenerator.

- System assessment relative to other conversion techniques.

- Studies on heat transfer and fluid dynamics associated with chemical/thermal regeneration of RTEC working fluid using concentrated solar flux.

- Thermochemical experiments designed to provide the experimental and theoretical basis for the design of an RTEC receiver/regenerator, and materials research necessary to identify feasible containment materials for fabrication of the receiver/regenerator will be conducted.

Heat Engine Analysis

The objective of the Heat Engine Analysis subtask is to analyze advanced energy conversion devices which show potential for meeting program goals in the mid- and long-term. Computer codes developed at Sandia can support analyses and trade-off studies of performance and economic capabilities. During FY1988, Sandia will continue to upgrade and utilize its library of programs to analyze heat engines for Distributed Receiver Systems.

Task 5. Direct Conversion

FY1988 Direct Conversion research is structured into the following subtasks:

- Direct Conversion of Solar Thermal Energy
- Solar Induced Surface Transformations of Materials.

Direct Conversion of Solar Thermal Energy

The objective of this subtask is to define and validate the feasibility of using high flux solar radiation (i.e., up to 2.5 MW/m^2) to initiate and sustain endothermic chemical reactions. The direct high flux can be used to generate the high temperatures necessary to initiate a reaction through mechanisms such as the production of free radicals. The free radicals may then be used to initiate chemical conversions which may be sustained using heat at a lower temperature.

Direct conversion efforts in FY1988 will include solar assisted chemical reaction research at the University of Houston, research of the solar detoxification of hazardous wastes at the University of Dayton, and research on the liquefaction of coal using solar thermal energy at the University of New Hampshire. The work at the University of Houston will emphasize catalytic hydrocarbon reactions with the potential for production of high-value compounds such as fuel additives and for upgrading of low value hydrocarbons such as straight chain paraffins to high value cyclic hydrocarbons. Work at the University of Dayton will focus on the solar detoxification of hazardous wastes which has been shown to have potential for significant cost and performance enhancements relative to conventional incineration techniques. Work on coal liquefaction, most likely at the University of New Hampshire, will emphasize a solar-unique process which may have the potential to convert over 50% of the carbon in coal directly to high value liquids such as benzene, toluene, and xylene. Major planned activities during FY1988 under this subtask are:

- Continuation of photo-assisted reactions research with emphasis on evaluation of the data base for the selection and definition of the best direct conversion candidates.
- Investigation of hydrocarbon reforming and cracking reactions by the University of Houston for production of high value compounds useful as fuel additives. Fundamental research will attempt to understand observations of rate enhancements of factors of up to 50,000 when a catalytic reaction mass is subjected to concentrated sunlight.
- Continuation by researchers at the University of Dayton, to investigate the enhancement of hazardous waste detoxification by the direct application of concentrated sunlight with emphasis on understanding the basic phenomena, on definition of a basis for a solar experiment to validate the concept, and on securing support and interactions from the Environmental Protection Agency.
- Investigation of the process of solar-assisted coal liquefaction with the objective of validating the basic concept.

Solar Induced Surface Transformations of Materials

The objective of this research is to identify, analyze, and understand beneficial transformations on material surfaces induced by highly concentrated solar radiation. These transformations may increase the durability, strength, toughness, and abrasion resistance in more cost effective processes than are now available to the materials processing industries, thereby having important military, aerospace, and transportation applications.

The goal for FY1988 is to study changes in the surface chemistry and structure of samples exposed to high solar fluxes in the Sandia Solar Furnace in order to determine: 1) extent of phase transformation on hardened samples; 2) extent of interdiffusion of cladding materials; 3) occurrence of impurity formation or unwanted surface compounds; and 4) unexpected beneficial effects. Research activities will include:

- Continuation of studying of the changes induced in the surface chemistry and structure of the target materials exposed in the Sandia Solar Furnace during FY1987.
- Selection of a promising area of solar induced surface transformations in which to concentrate initial effort, plan, and performance of new experiments for FY1988.
- Coordination of efforts at UH and GTRI for maximum effectiveness in the program. Work at GTRI will emphasize the preparation of carbon fibers with improved properties, applications of solar thermal technology to production of ceramic materials, and surface modification of materials by hypothermal treatment.

Task 6. Transport and Storage

The objectives of this task are to identify, understand, develop, demonstrate, and evaluate high-efficiency, low-cost energy transport and storage systems suitable for high-temperature (>400°C) solar thermal applications. The primary emphasis of this task is resolution of technological issues that affect the ability to confidently build a Central Receiver plant that uses molten salt. Specifically, commercial scale salt pumps and low-cost (packed) valves must be shown to perform well under the cyclic operation of a solar plant. Also, many operational benefits will accrue and parasitic power requirements will be reduced if ways can be discovered to lower the 230°C melting point of the sodium-potassium nitrate salt currently being used. Additions of water and/or calcium nitrate show promise of being able to achieve these benefits. Since the current emphasis in Distributed Receiver Systems technology is on the dish-mounted Stirling/electric system without thermal storage, minimal activity is contemplated for DR systems under this task. The following major activities are planned for FY1988 under transport and storage:

- Completion of documentation for the current generation Closed Loop Efficiency Analysis (CLEA) code.
- Continuation of full-scale testing of the molten salt pump and valve loops under the Category B experiments. This will include cyclical operation of the components to evaluate lifetime performance.
- Documentation of physical-chemical properties of salt/water solutions in order to reduce the melting point of the transport fluid, thereby reducing nighttime trace heating and warm-up heat energy requirements. The physical-chemical and thermal properties, chemical stability, and corrosiveness of ternary salt mixtures will be measured in FY1988, as these mixtures offer another potential option for reducing the salt mixture's melting point.

3. Systems and Applications Technology

Task 7. Innovative Concepts and Applications/Small Business Innovation Research (SBIR)

FY1988 research in this area consists of three subtasks:

- **New Ideas/Innovative Concept Development at Universities**
- **Small Business Innovation Research (SBIR)**

New Ideas/Innovative Concept Development at Universities

Innovative concepts research provides the Solar Thermal Research Program with a means for encouraging new ideas and innovative concepts from the vast pool of technical and practical knowledge in industry, universities, and innovators at large. The objectives of this task are to continue both of the 3-year innovative concepts projects which were funded in FY1986.

Research on both of the FY1986 projects were evaluated positively at the end of FY1987 and the second-year efforts were activated. The two innovative concepts projects are:

- Evaluation of the use of composite materials for stretched membranes by the University of California, Berkeley. Such an investigation over a three-year period should lead to a proof-of-concept and a scale-model evaluation of a membrane.
- Evaluation of an optical concept by the University of Chicago to achieve very high solar flux concentration by using a secondary concentrator. This work should lead to a proof-of-concept in a dish system within 2 years.

Small Business Innovation Research (SBIR)

The Small Business Innovation Research (SBIR) program is supported by DOE to encourage high-quality research or R&D proposals on advanced concepts concerning important energy-related scientific or engineering problems and opportunities that could lead to significant public benefit if the research is successful. The objectives of this program include stimulating technological innovation in the private sector, strengthening the role of small business in meeting Federal R&D needs, increasing the commercial application of DOE-supported research results and improving the return on investment from Federally funded research for economic and social benefits to the nation. Four SBIR contracts were awarded in FY1987 (SKI, LaJet, Dan-Ka, M.L. Energia) to develop concept feasibility in the areas of advanced concentrators and the direct use of concentrated solar flux. Funding of the second phase of these contracts will be determined in mid FY1988.

Task 8. Balance of Plant

This task will address research on the non-solar components necessary to construct, maintain, and operate a complete solar thermal system. Conventional balance of plant equipment constitutes a significant portion of solar thermal system costs. The primary goals of this task are the reduction of balance of plant capital costs, minimization of parasitic and auxiliary power requirements, and reduction of operation and maintenance costs.

The objective of this research task is to minimize the risk and expense associated with the operation and maintenance of solar thermal systems, principally through the development of innovative maintenance approaches and control systems that would allow for unattended operation. Benefits of automation in a Central Receiver plant include an estimated reduction in plant operating costs of 20-80% and a reduction in capital costs for heliostats of 2-5% (because the required number is reduced). Additional benefits include a potential increase in plant efficiency on clear days, a decrease in equipment failures, and prolonged component lifetimes.

In FY1988, a dynamic simulator developed in FY1987 will be extended to mimic a commercial scale solar power plant as defined by the Utility Study. The simulator will be used to evaluate a variety of control and operating strategies to maximize the output of the commercial plant.

Task 9. Central Receiver Systems

The integration of components and subsystems into a complete system is necessary to properly analyze the cost and performance tradeoffs and to identify critical technology development requirements. Central receiver systems and development activities include the development of designs, the analysis of system parameters, and the experimental testing of component groups, subsystems, and systems. The experimental testing of groups of components provides valuable data on subsystem interfaces and performance in a solar environment.

Several system studies are underway that involve applications of the solar central receiver technology. They are directed at understanding various design and economic tradeoffs in the context of actual data from the operating central receiver systems. These studies will indicate optimum techniques for reducing the delivered energy cost for central receiver systems while improving performance and reliability and decreasing risk. Major planned activities during FY1988 under this task are:

- Continuation of the Utility Study by a group of western utilities to address details of the conceptual design of the optimum plant, identification of technical uncertainties, and definition of the preferred next steps along the path to commercialize the Central Receiver concept.

- Continuation of the Annual Energy Improvement Study by refining the SOLERGY code validated in FY1987 to include expected component and subsystem reliability data. The value of redundancy will be assessed as will methods of improving performance and reducing parasitics.

- Extension of systems analysis of direct absorption receivers to include development of the best configuration for an internal film receiver with free flow of the heat transfer fluid over the interior or nonilluminated side of an external absorber plate.

- Analysis of issues including the effects of ultra low-cost stretched membrane heliostats on system design and performance, the impacts of trade-off of cost versus tracking errors for non-pedestal drives for stretched membrane heliostat systems, and the effects of hybridization for early market penetration.

Task 10. Distributed Receiver Systems

This task provides the systems engineering and analytical work needed to support the distributed receiver technology research being pursued with emphasis on requirements, constraints, trade-off studies, technical feasibility, and economics. It also provides conceptual (in some cases, preliminary or definitive) designs of systems and sub-systems and operates and maintains the Distributed Receiver Test Facility (DRTF).

The main emphasis of this research task is to model dish electric systems featuring Stirling engines and to evaluate modifications and upgrades made at the Solar Total Energy Plant (STEP), the world's largest solar plant using the cogeneration concept of energy production for an industrial application. Major planned activities during FY1988 under this task are to:

- Utilize the SOLERGY code to model performance of a variety of dish electric systems including those featuring free-piston and kinematic Stirling engines and the two Small Community Experiments.

- Evaluate recent modifications and upgrades at STEP to determine: 1) how well the modified and upgraded system performs in an intensive power production mode, and if actual performance meets predictions and validates systems analytical models; 2) how to best use the gas-fired superheater to optimize its effectiveness and lower the cost of energy production; 3) the relationship between supplemental energy added to the system by the fossil-fueled heater and that added by the superheater; 4) how to vary the three energy outputs (electrical, process steam, and chilled water) as a function of solar insolation; and 5) how to minimize the cost of energy produced through operating and control strategies.

Task 11. System Experiments

System experiments provide needed data on capital cost, performance, and operations and maintenance of complete solar thermal systems. The system experiments are conducted with major participation from solar equipment manufacturers and potential users. These experiments lead to the establishment of technical feasibility, the development of a cost and performance data base, technology exchange and discussions that can help in private sector decisions, and the identification of future research and development needs.

Starting in FY1988 the 10 MWe Solar Central Receiver Pilot Plant near Barstow, California (Solar One) will be operated in a "semi-commercial" mode with minimum government support. The work in FY1988 will provide valuable data on component and subsystem reliability, heliostat cleaning effectiveness, and short time interval weather data for a typical solar site. All of this information will improve the validity of the Annual Energy Improvement Study.

Two Small Community Solar Experiments are planned to evaluate a 100 kWe and a 250 kWe solar electric plant in small community utility environments. The 100 kWe (SCSE #1) plant will be located at Osage City, Kansas, and consists of four 25 kWe dishes using Barber-Nichols organic Rankine engines. The 250 kWe plant (SCSE #2) will be located at Molokai, Hawaii, and will consist of five Power Kinetics, Inc. (PKI) 291m^2 concentrators, which supply steam to five modules, each with 50 kWe steam/electric engines. During FY1988 SCSE #1 module verification with the new LaJet concentrator will be completed. The SCSE #2 module verification is scheduled to begin at the DRTF in January 1988 and the Molokai site construction is scheduled to begin in June 1988.

4. Planning and Assessment

Planning and assessment for the Solar Thermal Technology Program are conducted under the direction of the Technology Program Integrator (TPI) office located at the Solar Energy Research Institute (SERI). The TPI is the major advisory source to the DOE Solar Thermal Technology Program from which long- and short-range planning is derived, and the results of TPI activities directly influence the future directions of the Program. The TPI is responsible for the production and maintenance of a multi-year program plan (MYPP), and development of R&D goals and objectives with the laboratories managing the specific portions of the program.

The objective of the planning and assessment activity is to conduct program integration, assessment, comparative analysis, and specific technology exchange activities such as program documentation, workshops, and periodic contractor review meetings. Program planning and support activities in FY1988 will include continuing efforts to identify near-term high-value opportunities for solar thermal technology such as solar cleanup of contaminated water supplies and international opportunities. In addition, the TPI will continue coordination with industry and state government solar thermal activities to leverage DOE program efforts to the maximum practical extent.

The Solar Thermal Technology Program is responsible for a number of technology exchange activities to ensure prompt, accurate, and continuous flows of significant research and technology development information to industry and other users.

Each year, topical reports/publications are prepared and distributed by the Division to disseminate information about the status of the solar thermal technologies and projects. Also, each year several meetings/workshops are conducted by the Division to bring interested organizations as well as researchers, scientists, engineers, and users together in a technical forum to exchange technical and programmatic information. During FY1988 two major conferences will be conducted to share results from the program with interested parties. The first is a joint conference of Sandia and the Solar Energy Industries Association (SEIA) which will take place in Phoenix, Arizona in February 1988. SOLTECH 88 will deal with Solar Technologies for Energy Security and will include solar thermal systems for military applications as one of the topics to be discussed. The second, which will take place in Santa Fe, New Mexico during June 1988, will be the Fourth International Symposium on Research, Development and Applications of Solar Thermal Technology. DOE also participates in International Energy Agency (IEA) meetings and workshops.

IV. PROGRAM MANAGEMENT AND IMPLEMENTATION

A. Management Responsibilities

1. Headquarters, Lead, and Technical Centers

Within the Department of Energy, the Solar Thermal Technology Program is the responsibility of the Division of Solar Thermal Technology, which reports to the Office of Solar Heat Technologies.

Policy formulation, planning, and program evaluation activities are performed by DOE Headquarters with implementation of each element delegated to a field organization. The field management structure uses three types of responsibility and authority assignments: DOE Field Program Management, Technical Field Management, and Funded Support. The FY1988 assignments of these responsibilities are shown in Figure 5.

Figure 5.

SOLAR THERMAL TECHNOLOGY
FIELD RESPONSIBILITIES
(Fiscal Year 1988)

KEY ACTIVITIES	ALO	SAN	SERI	SANDIA
• RESEARCH			■	
• CENTRAL RECEIVER RESEARCH AND DEVELOPMENT	◆	◆		■
- Test Facility (CRTF) at SNLA				●
• DISTRIBUTED RECEIVER RESEARCH AND DEVELOPMENT	◆			■
- Test Facility (DRTF) at SNLA				●
• TECHNICAL PLANNING AND ASSESSMENT			■	
*SOLAR ONE — 10 MWe BARSTOW PROJECT				

◆ DOE PROGRAM MANAGER ■ TECHNICAL FIELD MANAGER ● FUNDED SUPPORT

2. Reporting Requirements

Management control over the Program is maintained through a schedule of periodic reporting and reviews to ensure that the program is proceeding as described in the field Annual Operating Plans submitted at the start of the Fiscal Year. Reports by the field managers to DOE Headquarters make up a pyramid of scheduled reports designed to keep program supervisors informed of development and work progress in a timely manner. These reports include:

- Weekly Significant Development Reports
- Quarterly Technical and Financial Reports
- Quarterly Review Presentations to DOE

Program control is exercised through approved field Annual Operating Plans. Any significant changes in work plans from those submitted and approved at the start of the Fiscal Year require approval by DOE Headquarters.

B. Program Planning and Evaluation

Overall, the progress of the program is evaluated against the R&D Program Plan objectives established by the Department of Energy and annually authorized (with funding appropriated) by Congress. In order to assess the progress of the Solar Thermal Technology Program on a regular basis, a formal set of controlled program milestones have been established. These milestones are reviewed and revised as necessary each fiscal year. The key activities in conducting program planning and evaluation are as follows:

a. Establishment of cost goals and periodic internal review of progress against these goals.

b. Establishment of a set of controlled program milestones to meet the cost goals (see Figure 4, Section III) and periodic internal review of progress against these milestones.

C. Program Resources

Table 2 (Section III) presents a summary of the Solar Thermal Technology Program budget for Fiscal Year 1988. The budget information is arranged by Work Breakdown Structure task elements and is distributed according to funding recipients.

D. Procurement Execution Plan

1. Procurement Strategy

Most procurements for the Solar Thermal Technology Program are handled by the field management organization responsible for each program element. At the beginning of the fiscal year, funds are disbursed to the field management organizations upon approval of their respective Annual Operating Plans. Each Annual Operating Plan submitted by the field management organizations includes a procurement plan. These plans are control documents, and any significant changes in the operating plans of a field management organization must be approved by DOE Headquarters.

2. Procurement Policy and Procedures

With few exceptions, procurements in this program are competitive. Noncompetitive procurements require specific justification. Fixed-price contracts are sometimes used when practical, but for procurements involving research or development to meet a functional or performance objective, cost-plus-fixed-fee contracts are usually awarded. Cost-shared research and development contracts are used under the Federal Financial Assistance Regulation.

Field management and organization procurement procedures are similar to those of DOE Headquarters. In cases where procedures differ (resulting in an impact on the program), appropriate measures are taken to ensure that programmatic requirements are met. It is also the policy of the Solar Thermal Technology Program to maximize the use of small and minority businesses whenever possible.

3. Fiscal Year 1988 Planned Procurements

Table 3 lists the major procurements planned for FY1988 using FY1988 funds as well as activities using FY1987 carryover funds.

Table 3. MAJOR FY1988 PLANNED PROCUREMENTS

TITLE/ACTIVITY	FIELD ORGANIZATION
COLLECTION TECHNOLOGY	
1. Optical Materials	
• Sol-Gel Mirror Processing	Sandia - DR
• Polymer Research	SERI
• Reflective Materials Soiling Protection	SERI
• Mirror Materials Protection	SERI
2. Concentrators	
• Stretched Membrane Concentrator Development	Sandia - DR
• Structural Analysis Support	Sandia - DR
• Solar Collector Pedestal Fabrication	Sandia - DR
• Stretched Membrane Heliostat Development	Sandia - CR
• Membrane Dish Optical Performance	SERI
• Wind Effects Research	SERI
• Dish Structural Analysis	SERI

Table 3. MAJOR FY1988 PLANNED PROCUREMENTS - Continued

TITLE/ACTIVITY	FIELD ORGANIZATION
3. Receivers	
● Heat Loss Studies	Sandia - DR
● Receiver Code Development	Sandia - DR
● Reflux Receiver Development	Sandia - DR
● CAESAR Catalyst Development	Sandia - DR
● Technical Support	Sandia - DR
● Direct Absorption Receiver Testing	Sandia - CR
● Direct Absorption Receiver Design	Sandia - CR
● Direct Absorption Receiver Research	Sandia - CR
● Materials for Blackeners	SERI
CONVERSION TECHNOLOGY	
4. Heat Engines	
● Free Piston Stirling Engine Phase II	Sandia - DR
● Engine Test Facility Construction for Kinematic Stirling Engine	Sandia - DR
● Gas Combustor for Kinematic Stirling Engine	Sandia - DR
● Receiver/Regenerator Research for Regenerative Thermoelectrochemical Converter (RTEC)	SERI
5. Direct Conversion	
● GTRI Research on Solar Materials Processing	SERI
● University of Houston Photochemical Research	SERI
● Solar Assisted Hazardous Waste Detoxification Research	SERI
6. Transport and Storage	
SYSTEMS & APPLICATIONS TECHNOLOGY	
7. Innovative Concepts & Applications/Small Business Innovation Research	
● New Concepts Research	SERI
8. Balance of Plant	
9. Central Receiver Systems	
● Operation & Maintenance of Solar Thermal Test Facilities	Sandia - CR
10. Distributed Receiver Systems	
● Dish-Electric System Studies	Sandia - DR
● Shenandoah Tests	Sandia - DR
● TBC/Acurex Concentrator Analysis	Sandia - DR
INFORMATION DISSEMINATION	
● Solar Heat Documentation Project	Sandia - CR,DR