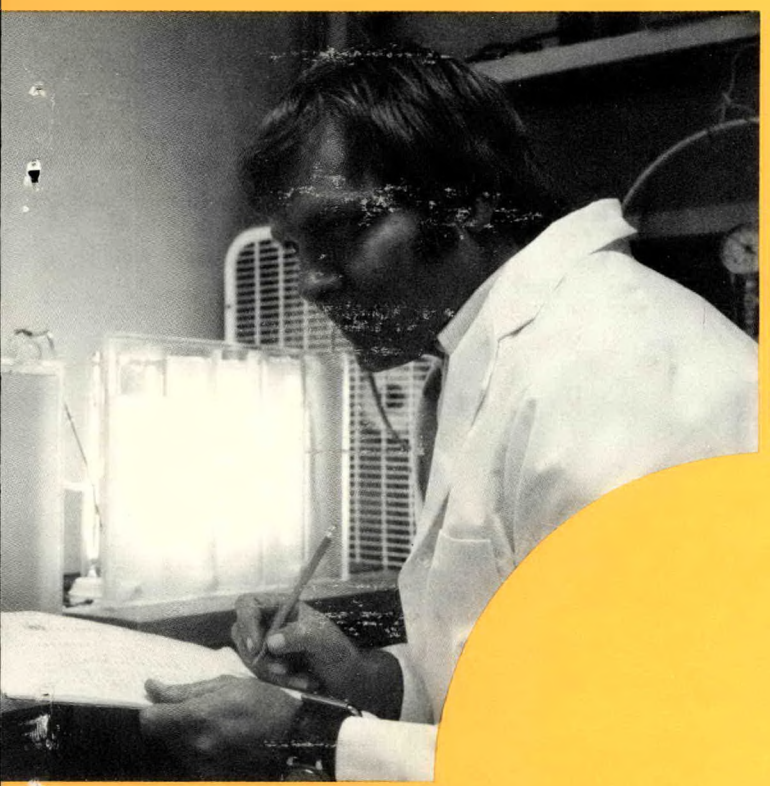
SERI/MR--200-1466R

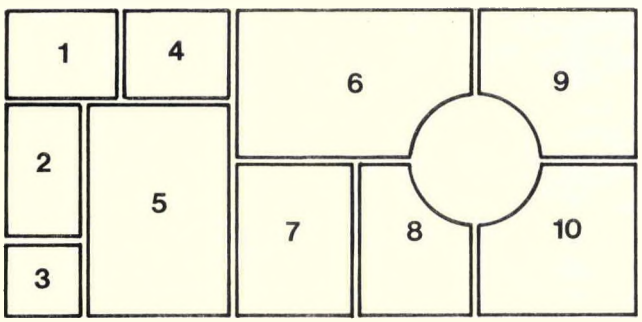
DE83 014247

Solar Energy Research Institute

Institutional Plan FY 1982-FY 1987



Cover Photographs



1 Concentrating collectors mounted at SERI Test Facility **2** Biomass gasification laboratory **3** Testing a flash evaporation concept for ocean thermal energy conversion **4** Demonstration of the flexibility of fusion-drawn glass **5** Algae cultivated to produce gaseous fuel **6** Feeding photosynthetic bacteria to produce hydrogen gas **7** Edge-supported pulling technique for producing silicon sheet solar cells **8** Monitoring air gasification counterflow gasifier **9** Test array of photovoltaic cells **10** Spectroscopic analysis of photovoltaic cell composition

Solar Energy Research Institute

Institutional Plan FY1982-FY1987

January 1982

DISCLAIMER

SERI

Solar Energy Research Institute

Operated for the U.S. Department of Energy

1617 Cole Boulevard
Golden, Colorado 80401

TABLE OF CONTENTS

	Page
I. Director's Overview	1
Introduction	3
SERI's Mission	4
Growth and Consolidation	5
The Four Major Research Areas	10
Solar Electric Conversion Research Division	10
Solar Fuels and Chemicals Research Division	11
Solar Thermal and Materials Research Division	11
Supporting Activities	12
Principal Responsibilities	12
Looking Ahead	12
Summary	14
II. Scientific and Technical Activities	15
A. DOE Program Effort	20
1. Current Programs	20
a. Assistant Secretary for Conservation and Renewable Energy (AS/CE)	20
Photovoltaics	20
Wind	26
Alcohol Fuels	29
Biomass	35
Energy Storage	40
Thermal	43
Active	47
Passive	50
Information	53
b. Director of Office of Energy Research	56
Materials Sciences	56
Biological Energy Sciences and Chemical Sciences	58
Advanced Energy Projects	61
2. New Initiatives	63
a. Assistant Secretary for Conservation and Renewable Energy (AS/CE)	63
Photovoltaics	63
Energy Storage	65
Ocean Energy Research	66
Thermal	70

TABLE OF CONTENTS (Concluded)

Page

Active 73
Passive 77

b. Director of Office of Energy Research 79

Materials Sciences 79
Biological Energy Sciences 86
Chemical Sciences 87
Engineering, Mathematical, and Geosciences 89

B. Work for Others 93

U.S. Department of Defense 94
U.S. Agency for International Development 98
U.S. Department of Interior 100

III. Personnel Resources 101

Present Capability 103
Personnel Trends 104
Personnel Requirements 105

IV. Site and Facilities Development 107

Introduction 109
SERI Permanent Laboratory and Office Facility 109
Laboratory Site Development 109
Present Facilities 109
Facility Costs 111

SECTION I

DIRECTOR'S OVERVIEW

SECTION I

DIRECTOR'S OVERVIEW

Introduction

The Solar Energy Research Institute (SERI) was established by Congress to perform research, development, and related functions as necessary to establish solar energy as a viable part of our national energy resources. SERI's present role is to conduct high-risk, high-payoff research and development on renewable energy resources in order to advance scientific understanding and establish a technological base so that private enterprise may choose energy production options for demonstration and commercialization in the competitive marketplace.

The legislation that created SERI defined solar energy as " . . . energy which has recently originated in the Sun, including direct and indirect solar radiation and intermediate solar energy forms such as wind, sea thermal gradients, products of photo-synthetic processes, organic wastes, and others." From this broad range of solar energy sources, SERI explores new ideas and focuses its research and development efforts on certain particularly promising technologies.

In the National Energy Policy Plan submitted to the Congress in July 1981, the Department of Energy (DOE) stated a number of guiding principles for the role of the Federal Government in energy issues. Generally, the Plan states that the overriding concern of the Federal Government is to establish sound, stable, public policies that will encourage the public and private sector to produce and use energy wisely and efficiently. Specifically, the Plan states,

> " . . . Federal spending should be considered only in those promising areas of energy production and use where the private sector is unlikely to invest. . . . Public spending is appropriate (and will continue) in long-term research with high risks, but potentially high payoffs."

We view high-risk research and development initiatives as those for which technical feasibility is difficult to ascertain or the probable time for development and payoff is so long that private industry, despite its interest, cannot reasonably be expected to undertake itself. We view potentially high-payoff research as that which, with the development of cost-effective new technologies, may result in wide benefits to the nation through some combination of reduced energy costs, reduced vulnerability to disruption of foreign energy supplies, reduced outflow of American capital, creation of new jobs, increased productivity, and positive impact on the quality of our natural environment.

SERI's activities will be performed consistent with the solar energy related activities and roles of the universities, other national laboratories, and industry. This country's great research universities are the major source of the fundamental scientific knowledge necessary for the development of our energy resources. Solar energy is no exception and SERI intends to cooperate and to work in close concert with university researchers on the one hand while also maintaining close contact with industrial technology.

SERI's Mission

In its first years of operation, SERI was called upon to perform work in many areas other than the focused research and development now emphasized. Thus, the Institute was involved in many market-related and other studies, including policy and program planning, management of international solar programs, socioeconomic and environmental studies, public information dissemination, projects to accelerate the commercialization of solar technologies, and program and contract management. This proliferation of activities and the rapid increase in staff with the diversity of skills needed to carry them out inevitably caused difficulties to the young, expanding organization. Constant change in size and organization hindered the Institute's ability to assure the effectiveness of its fundamental research and development mission.

Accordingly, during the past year, SERI has undertaken and accomplished a major redirection of its mission and activities. This redirection permits a more focused effort in the areas we believe have the highest potential, and is consistent with the sharper definition of the government's role in energy research and development as expressed in the National Energy Policy Plan.

Our present mission emphasizes:

1. Solar Electric Conversion. This area includes the direct conversion of sunlight into electricity. Primary areas of investigation are photovoltaics, photoelectrochemistry, and wind. SERI will also continue to be the lead center for photovoltaics advanced materials and devices.
2. Solar Fuels and Chemicals. This area will be directed toward the development of efficient photoconversion processes for the production of fuels and chemicals from sunlight and renewable resources. Areas of investigation are biotechnology, thermochemistry, photochemistry, and photobiology. Applications include the production of hydrogen, methanol, ethanol, and other solar derived fuels and chemicals.
3. Solar Thermal. SERI has assumed a leadership role in many low and intermediate temperature solar thermal research areas, including low-cost collectors, thermodynamics, low-temperature heat engines, building components, heat transfer mechanisms, and storage. SERI's principal research activities would continue in these areas. Primary areas of investigation are active and passive heating and cooling, thermoelectric conversion, solar ponds, and utilization of indirect thermal conversion mechanisms.
4. Materials Sciences and Research Support. A strong research staff is needed to perform research in related fields relevant to SERI's primary areas of emphasis. Available SERI capabilities in materials research, systems engineering, measurement and testing, renewable resource assessment, and other fields will provide a necessary resource base that can be drawn upon by researchers at SERI, and other public and private organizations.

In order to assure that the Institute's research priorities are based on the best information available, SERI intends to strengthen its technical staff in the appropriate areas and to maintain a close and continuing dialogue with the scientific, engineering, and industrial communities. In this regard, the redirection of SERI's mission has made it necessary to restructure its external advisory committees to emphasize the basic research areas. We are now establishing new advisory committees and inviting nationally recognized

authorities and leaders from industry, universities, and other research laboratories to participate. We expect this new advisory structure to be in place early in calendar year 1982, and anticipate that the guidance provided will greatly enhance SERI's research capabilities and ability to establish research priorities.

Looking to the future, we see SERI's specialized research staff and facilities providing the nation with energy science research pertinent to the development of renewable energy technology. We also see SERI providing a knowledge base, facilities, and expertise, and serving as the cutting edge research organization for an emerging renewable energy industry. This industry is of great potential benefit to the nation. SERI's supporting research will contribute significantly to realizing this potential.

Growth and Consolidation

SERI's initial growth and direction reflected the varied programmatic requirements placed upon the new organization. With the move to a more circumscribed mission, a leveling off in such growth and a consolidation of both staff and programmatic activities have occurred. Figure I-1 shows SERI's current organization. Figures I-2 through I-7 detail the changes that have occurred in staff, subcontracting and procurement, and in major program content.

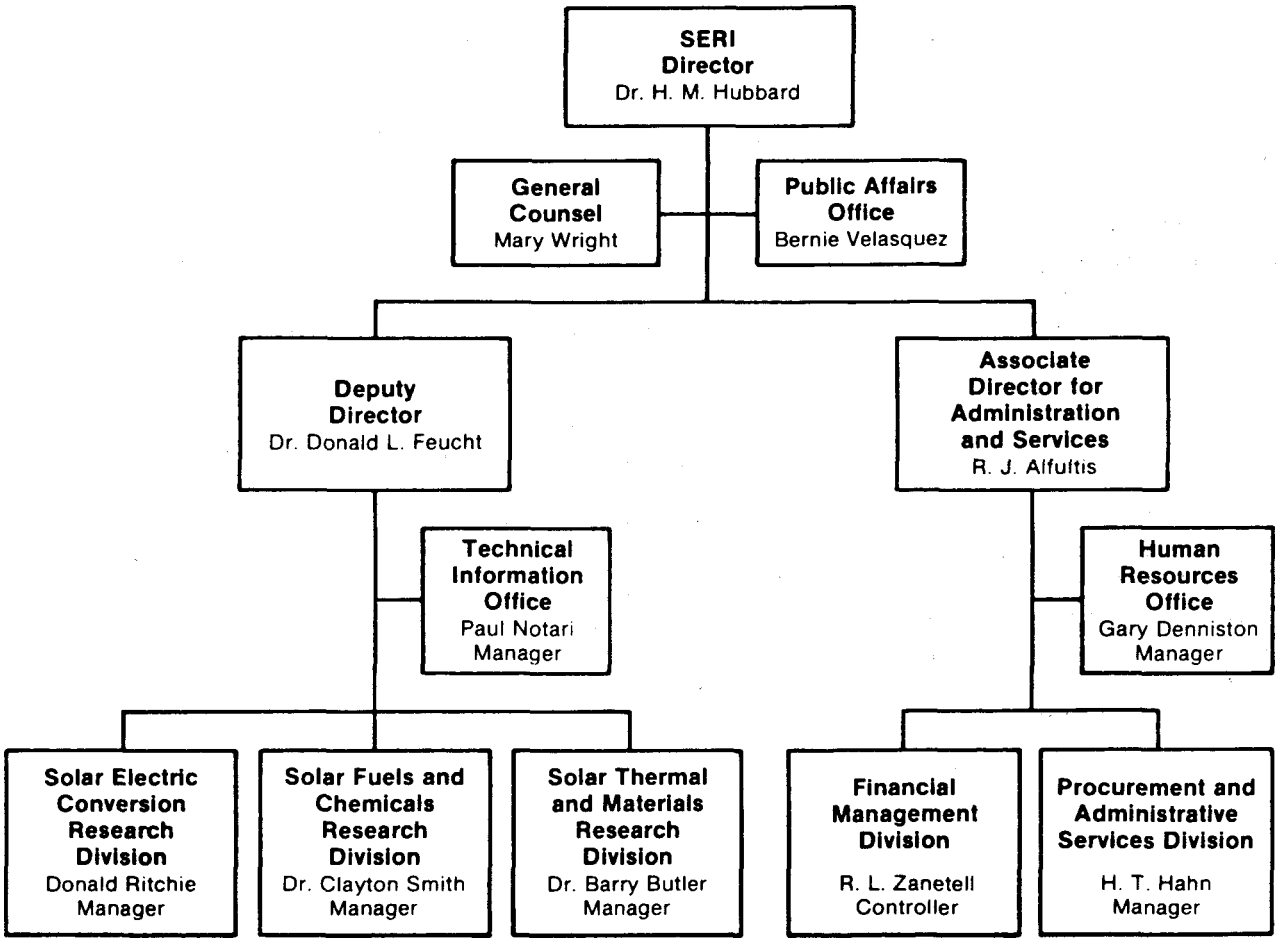


Figure I-1. Current SERI Organization

Figure I-2 shows SERI's staffing levels at the beginning of each fiscal year. The permanent staff expanded rapidly in size through FY 1979 as new responsibilities were assigned to the Institute. Because many projects required very fast startup or were expected to be of short duration, a substantial number of temporary agency personnel were added to complement the permanent staff.

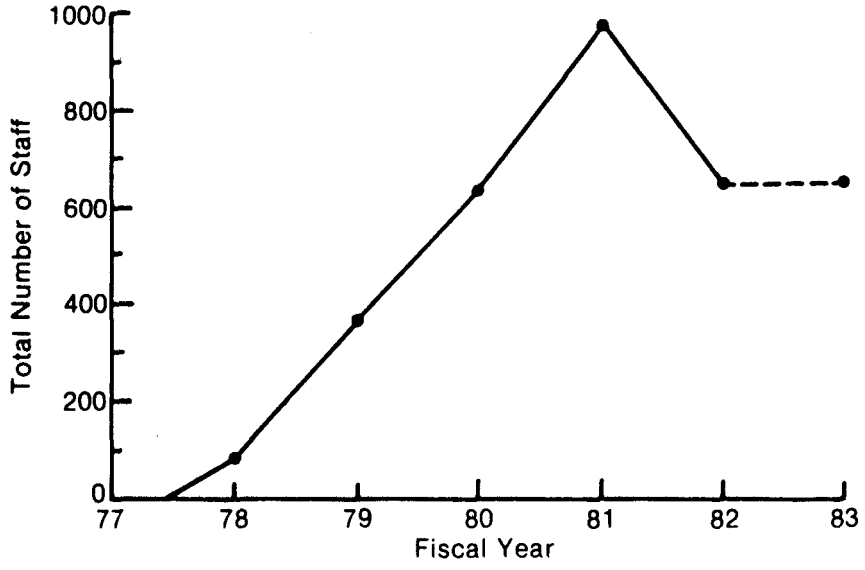


Figure I-2. SERI Staffing Levels FY 1977-1983

As SERI's activities have stabilized under the redirection of its mission, the practice of supplementing the permanent staff with temporary agency personnel has all but ceased, and is now limited to instances of very short duration. The permanent staff also has been reduced, eliminating positions in areas other than those needed to accomplish our basic mission. We are carefully strengthening our scientific, technical, and engineering staff as well as our management capability, primarily by adjusting our skill mix as appropriate for our research mission. Through the remainder of this planning period, we expect permanent staff levels to stabilize very near our present strength.

Figure I-3 presents the number of direct staff contributing to our four major research areas' activity as a percentage of all SERI direct staff for FY 1981 through FY 1983. (Direct staff are those accountable to program tasks as opposed to overhead funding.) This illustrates the major shift in SERI's program emphasis. The major research areas now comprise a significantly greater percentage of SERI's total staff than they had in the past, and the staff is considerably more permanent in nature. This permanent staff is the foundation supporting the quality of research activity at the Institute.

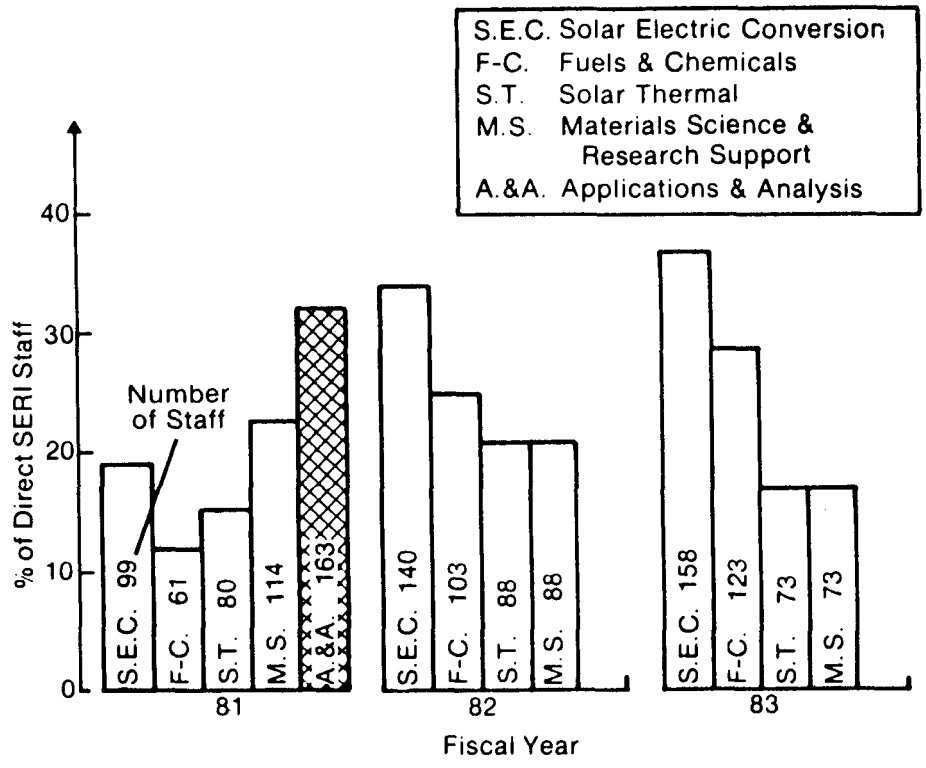


Figure I-3. SERI Direct Staff Allocation to Major Research Areas

The rapid increase in program responsibility assigned to SERI from 1978 to 1980 required the subcontracting of a substantial amount of work. Figure I-4 shows SERI's subcontracting and procurement history and indicates a trend toward decreasing subcontracting and total external purchases. This decrease is due to the reduction in the number and types of programs that SERI supported prior to our transition and does not represent any move away from a proper working relationship with private industry.

Subcontracts and the purchase of miscellaneous services are expected to continue to decrease as a percentage of SERI's operating budget. As a research laboratory, SERI should carry out most of its activities "behind the fence." However, it is imperative that SERI maintain an active contracting program with industry and a sound cooperative relationship with the national research community. This suggests that future subcontract activities should be maintained in the range of 15%-35% of the operating budget.

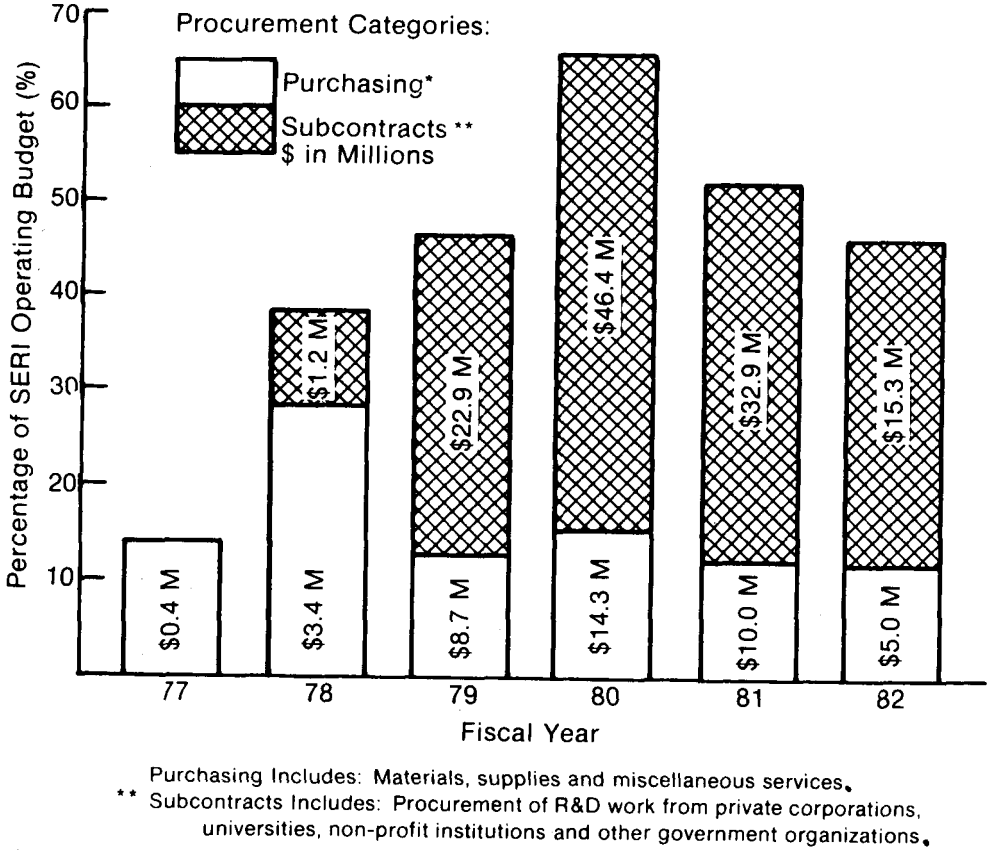


Figure I-4. Subcontracts and Purchasing as Percentage of Operating Budget

Figure I-5 illustrates the continuing balanced distribution of SERI's subcontract activity among universities and private industry, with a small percentage going to other laboratories or government agencies. This distribution should remain relatively constant, reflecting SERI's intentions to continue to work with the private sector and to maintain strong ties with the university community. The proportion of funding contracted with small businesses has steadily increased and has reached 34.6% in 1981. This percentage includes 2.9% in subcontracts to disadvantaged and women-owned businesses. In FY 1982, we estimate that 30% of the total will be subcontracted with small businesses, of which 5.3% will be with disadvantaged or women-owned businesses.

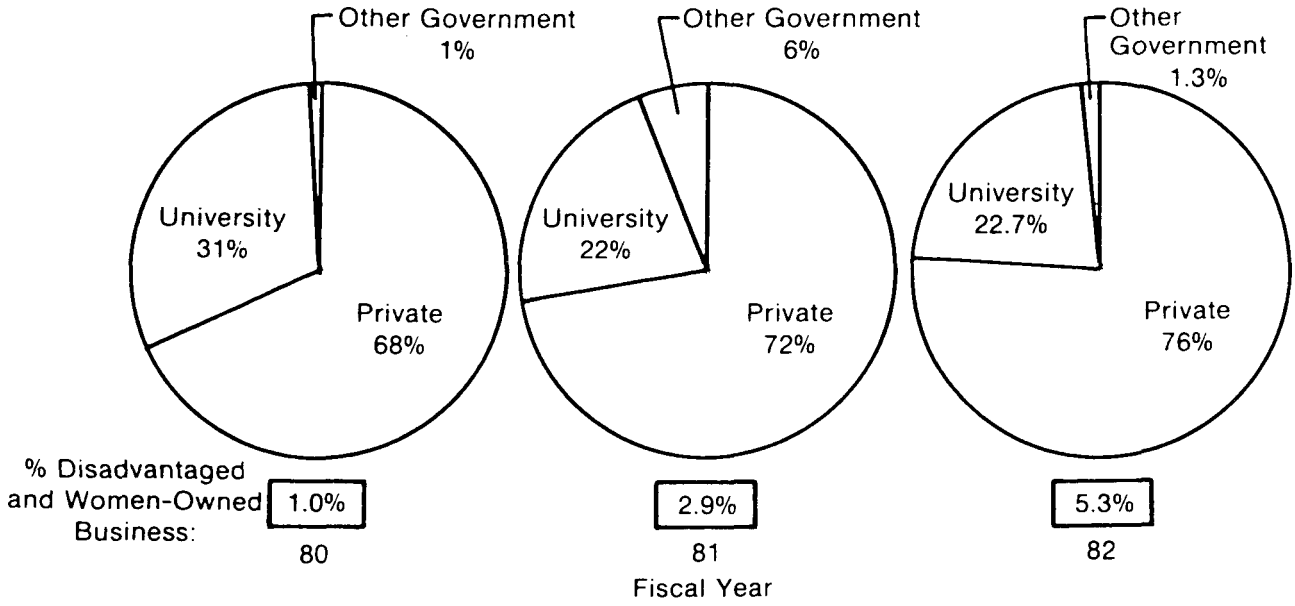


Figure I-5. Recipients of Subcontracts

Figure I-6 provides a history of SERI's major program elements by funding level between FY 1977 and the present. It indicates clearly the Institute's very rapid growth from a $3.6 million operating budget in FY 1977 to close to $100 million in FY 1980, due to the unique nature of the project). This figure also shows the dramatic decline of overall operating funds for the Institute in FY 1981 and FY 1982, the elimination of some programs, and the concentration of effort on research.

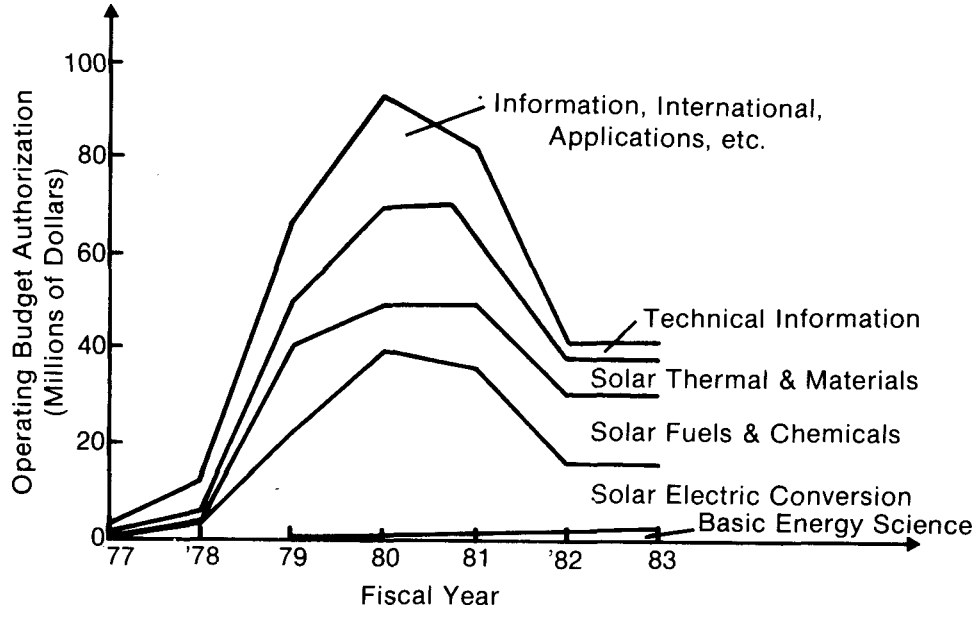


Figure I-6. SERI Program Elements History

Finally, Fig. I-7 defines the current areas of emphasis as a percentage of Institute effort from 1977 to 1984 and beyond. This figure shows the phasing out of commercialization and other nonresearch and development activities, and a relatively constant percentage of effort for the current areas of emphasis for this planning period.

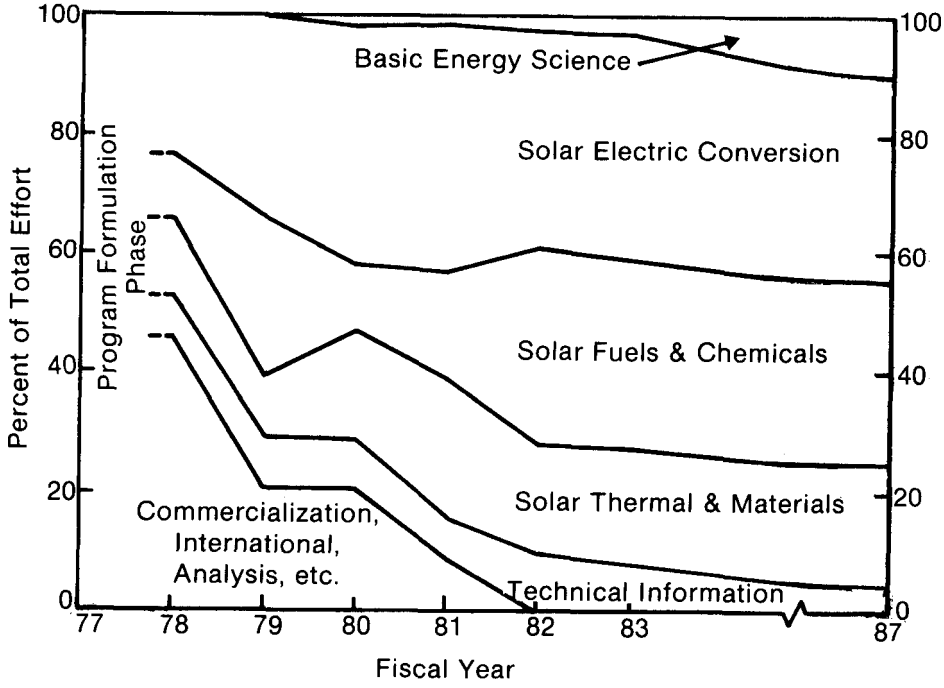


Figure I-7. SERI Program Elements History

The Four Major Research Areas

Figure I-7 illustrates the Institute's major research efforts: solar electric conversion, solar fuels and chemicals, low and intermediate temperature solar thermal processes, and materials and other support research. Basic Energy Science is presently a small but important activity at SERI. In the future, we plan to increase this research activity because it contributes to the technology base for our other major programs. SERI's recent redirection, as well as the steps we are taking to strengthen technical, scientific, and management resources, will bring added progress in these areas. These resources will also place the Institute in a position to accept additional research responsibilities in line with our mission.

SERI's research efforts are grouped into three divisions: Solar Electric Conversion Research, Solar Fuels and Chemical Research, and Solar Thermal and Materials Research. The primary activities of each division are summarized in the following sections.

Solar Electric Conversion Research Division

The Solar Electric Conversion Research Division is primarily involved in photovoltaics research, which is the largest single program at SERI. The Division is responsible for management of the photovoltaics advanced research and development program and the

innovative wind energy systems program. The Division also has a significant technical capability for the assessment of renewable energy resources.

SERI photovoltaics research is intended to investigate innovative concepts, materials, and structures to demonstrate the technical feasibility of new solar cells. The objective is to advance scientific understanding and to establish a technology base for industrial use. SERI's early effort to build a laboratory of excellence in photovoltaic research has resulted in an impressive functional inventory of advanced laboratory research equipment used for both SERI research activities and as research support of subcontracted activities. The Division's device and materials characterization capabilities are now recognized as a unique and independent assessment resource that is not possessed by any single photovoltaic company or university.

Solar Fuels and Chemicals Research Division

The Solar Fuels and Chemicals Research Division applies the chemical and biological sciences along with related engineering disciplines toward development of new concepts for the production of fuels and high-energy chemicals. The Division conducts research and manages contracts in the production and conversion of biomass as well as the direct use of solar energy through photoconversion to chemical potential energy. Typical project areas are new processes for the production of hydrogen via water splitting, microalgal production of oils, and conversion of wood to fuel alcohols.

The Division has obtained international scientific and industrial recognition through its work in photoelectrochemistry, biomass thermochemistry, biotechnology, and high efficiency alcohol fuel utilization. Through the Division's capability in basic research and vision toward technology applications, a continued high level of creative efforts is anticipated. This will measureably strengthen the fuels and chemicals energy technology base and provide industry with new options for future products and processes.

Solar Thermal and Materials Research Division

The Solar Thermal and Materials Research Division is responsible for the Institute's work in the other two principal research areas—solar thermal processes and materials and other supporting research. Activities in the solar thermal processes area include active, passive, and hybrid heating and cooling systems; solar thermal technology, primarily for industrial and utility applications; thermal energy storage; and ocean energy conversion. The private solar thermal energy industry consists primarily of small businesses that lack the resources to perform basic research in new materials or components. SERI provides this industry with a center where this research is performed and the results are integrated into prototype systems that industry can use to expand or improve its products.

The materials and other supporting research performed in this Division contributes to the division's other research activities, but principally identifies and develops promising materials for solar thermal systems. These include materials for absorbing, transmitting, and reflecting solar radiation; materials for advanced structural support; and working fluids. Like the solar thermal processes area, this work addresses research and development that most private companies within this industry cannot support.

Supporting Activities

SERI conducts a variety of activities in Basic Energy Research for the DOE Office of Energy Research. These activities are performed in the three research divisions and are essential in establishing the scientific base necessary for future progress in specific renewable technologies.

SERI's Technical Information Office provides information products and services in each solar program area. The Office also manages the Solar Energy Information Data Bank, a national network of solar energy technical information service organizations. The technical information function at SERI assures effective communication regarding the progress of research activities among the various entities involved in and benefiting from solar energy research. The goal is to disseminate technical information to targeted technical audiences at other laboratories, universities, and in the private sector.

Principal Responsibilities

DOE has designated SERI as Lead Center for Photovoltaic Advanced Research and Development. This is foremost of ten such principal responsibilities DOE has now invested in the Institute. The complete list includes:

- Lead Center for Photovoltaic Advanced Research and Development
- Solar Thermal Research and Advanced Development
- Thermal Energy Storage Research, Analysis, and Assessments
- Ocean Systems Advanced Research and Development
- Alcohol Fuels Research and Development (Process and Advanced Utilization)
- Biomass
  - Aquatics Research and Development
  - Anaerobic Digestion Research and Development
  - Biological Hydrogen Research and Development
- Active Heating and Cooling Collector Coordination
- Innovative Wind Energy Systems
- Solar Energy Technical Information Compilation and Product Development

Looking Ahead

SERI's ability to carry out cost-effective programs and to retain a top quality staff will be greatly enhanced by completion of permanent facilities. Recent acquisition of a permanent site was a major step toward this end. The present leased quarters provide excellent office space but are severely limited and costly when used for experimental purposes. Construction of a large facility is not necessary or even desirable at this time. The current facilities plan is modular and can be implemented as funds become available over several years. Over the long term, permanent facilities will be more cost effective than leased facilities and will enhance accomplishment of SERI's mission.

For research and development organizations to operate effectively, there must be a sense of stability and continuity. The uncertainties in the renewable energy budget, both with respect to total amount and distribution by program, have made it very difficult to provide such continuity and stability. An equally important concern, particularly in a time of reduced energy research and development funds, is the need for efficient use of available funds. The President's economic recovery program is based in large part on reducing federal expenditures, and consequently, major reductions in energy research and development funds are being made. As this trend has developed, SERI found it cost effective to reduce diversification and concentrate more on specific research areas. We believe this enables SERI to accept more research and development work in line with our mission. Figure I-8 shows SERI's total allocation of the Federal solar budget. We believe that it is consistent with the efficient allocation of these very limited research funds to devote a larger percentage to organizations specifically targeted on a clearly defined mission in the solar energy field. While there are a variety of organizations necessary to properly perform the national research program there is clearly an opportunity to focus more of the reduced budget at these organizations and thereby realize more productive use of research funds.

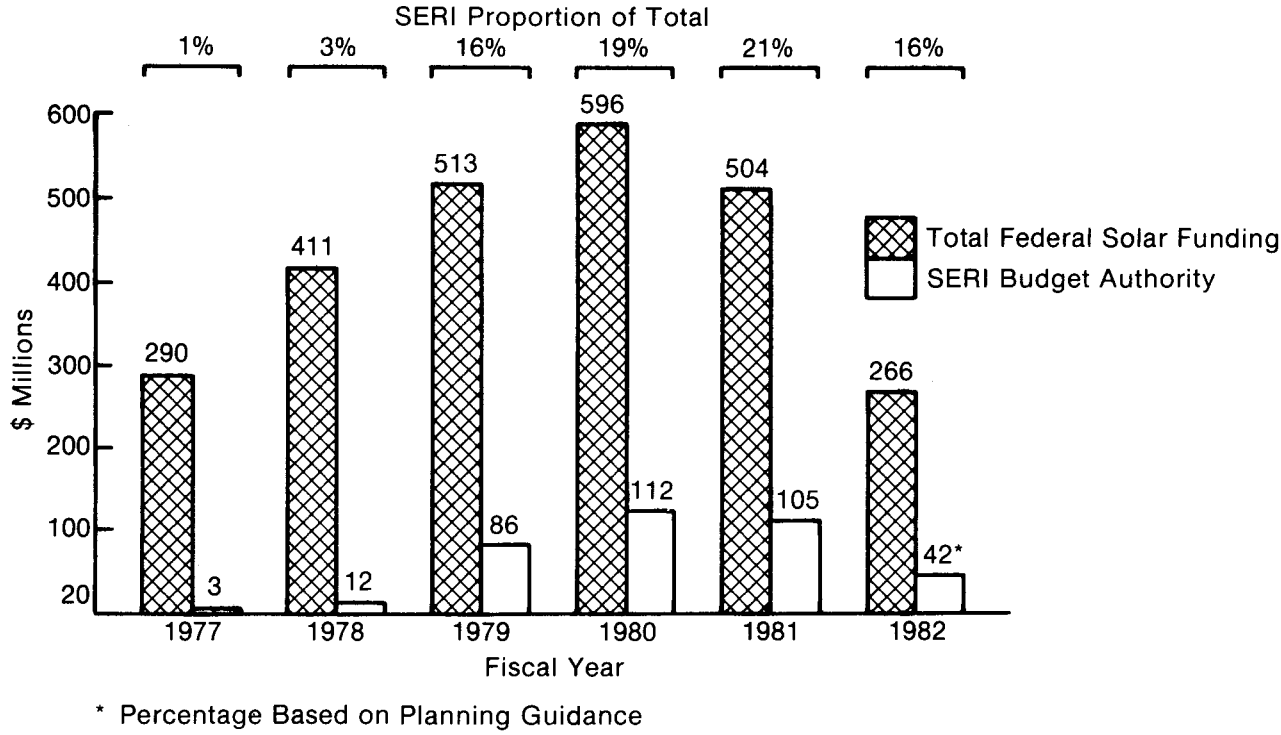


Figure I-8. SERI Proportion of Federal Solar Budget

Summary

SERI has completed a major transition to a focused solar research program and has the staff resources well-suited to the new mission. Through improved management of our present resources and selective additions to the scientific staff, we are moving aggressively to establish the value of our research to the nation. We are prepared to accept additional research responsibilities in line with our mission and we look forward to working in concert with the public and private sectors to ensure a proper national contribution to solar energy research.

H. M. Hubbard, Director

SECTION II

SCIENTIFIC AND TECHNICAL ACTIVITIES

SECTION II

SCIENTIFIC AND TECHNICAL ACTIVITIES

This section contains a detailed description of SERI's scientific and technical activities in support of DOE and other sponsoring organizations. The vast majority of SERI's activity is sponsored by DOE, and in particular, by the Assistant Secretary for Conservation and Renewable Energy (AS/CE). A small but growing portion of SERI's activity is sponsored by the Director of the Office of Energy Research (D/OER). SERI also performs limited research activities in support of other federal agencies such as the Departments of the Interior and Defense, and the Agency for International Development.

The research activities described in this section emphasize longer term research, provide a focus on a limited number of specific high priority fields, and are in keeping with SERI's goal of becoming the national center of research excellence in renewable energy technology. This technology base is, and will continue to be, used by the private sector to profitably introduce renewable energy into our nation's energy future.

Table II-1 provides an overview of Section II. Each research area being investigated at SERI is shown along with the SERI organizational unit primarily responsible for conducting the research, the major thrusts of the research, either as a current program or a proposed new initiative, and the anticipated funding. The funding shown for each initiative is FY 1982 unless otherwise noted.

These activities strive to (1) explore new ideas; (2) ensure a basic understanding of solar energy related scientific phenomena; and (3) conduct research and development in those renewable energy technologies which have the most promise of ultimately competing in the marketplace and which are most likely to contribute to a strong mix of economically viable energy production technologies.

Table II-1.
SERI Scientific and Technological Activities

Research Area (Organization)	Major Thrusts and Funding	
	Current Program	New Initiatives
DOE AS/CE		
Photovoltaics (SEC) (p. 20; 63)	Amorphous materials; polycrystalline and thin films; high efficiency concentrator cells photo-electrochemical cells; device characterization; insolation resource assessment. 16.0 M	Solid state research; new PV materials; device degradation; enhanced insolation resource assessment. 4.2 M
Wind (SEC) (p. 26)	Advanced and innovative concepts; turbine noise; utility interface modeling and analysis. 1.6 M	To be determined.
Alcohol Fuels (SFC) (p. 29)	Yeast genetic engineering; cellulose bio-conversion; biotechnology processes; biomass/ gasification; pretreatment and by-products utilization; advanced engines; advanced methanol fuel cells. 8.0 M	To be determined.
Biomass (SFC) (p. 35)	Aquatic species; anaerobic digestion; photo-biological hydrogen; thermochemical/electro-chemical conversion. 5.9 M	To be determined.
Energy Storage (SFC) (p. 40; 65)	Solar thermal storage concepts; thermal energy transport techniques. 1.1 M	Thermally regenerative electrochemical systems (TRES). 0.5 M
Thermal (STM) (p. 43; 70)	Materials durability improvements; low-cost concentrator concepts; energy conversion heat transfer mechanisms; materials characterization. 4.0 M	Polymer research; thin glass reflector encapsulation; reflector concept development; wavelength/flux separation. FY 1983 6.2 M
Ocean (STM) (p. 66)	This is an ongoing program at SERI but was included as a New Initiative based on the Administration's budget request for FY 1982.	Low pressure steam turbine concepts; direct contact heat exchangers; wave energy conversion devices. 2.1 M
Active (STM) (p. .47; 73)	Improved glazings, coatings, and polymers for flat-plate collectors; innovative collector concepts; solar cooling. 1.2 M	Innovative low- and medium-temperature concentrating collectors, solar ponds research. FY 1983 1.3 M
Passive (STM) (p. 50; 77)	Heat transfer in passive systems; collection and analysis of building performance data; thermal performance calculation procedures; passive manufactured buildings. 1.4 M	Solid-to-solid phase change storage; innovative window technology. FY 1983 1.2 M
Information (TIO) (p. 53)	Information needs research; information product development and transfer; information program coordination. 3.2 M	None proposed.

SEC = Solar Electric Conversion
SFC = Solar Fuels and Chemicals
STM = Solar Thermal and Materials
TIO = Technical Information Office

Table II-1.
SERI Scientific and Technological Activities (concluded)

Research Area (Organization)	Major Thrusts and Funding	
	Current Program	**New Initiative**
DOE/OER		
Materials Sciences (STM) (p. 56; 79)	Materials degradation; new materials options. 0.2 M	Thermoelectric materials; neutralization of low energy ions; low-temperature metalization by thermal decomposition; new electrode materials for photoelectrochemical cells; electronic structures of semiconductors; nucleation and growth of semiconductor films; superlattice concepts. FY 1983 0.9 M
Biological Energy Sciences (SFC) (p. 58; 86)	Photosynthetic microorganism energy conversion. 0.1 M	Microalgae production of oils. FY 1983 0.1 M
Chemical Energy Sciences (SFC) (p. 58; 87)	Synthetic photoreaction centers; semiconductor-electrolyte interfaces; molecular synthesis and catalysis. 0.4 M 0.4 M	Electrochemical conversion of biomass into chemicals; primary and secondary pyrolysis of natural carbonaceous solids. FY 1983 0.2 M
Advanced Energy Projects (STM) (p. 61)	Thin-film thermoelectric devices. 0.1 M	None proposed.
Engineering, Mathematical, and Geosciences (STM) (p. 89)	No current programs.	Stability of double-diffusive processes; two-phase flow heat transfer research; direct contact heat transfer; jet condenser fluid dynamics. FY 1983 0.8 M
Work For Others		
Department of Defense (SEC, SFC, STM) (p. 94)	Solar pond design and evaluation; *Renewable Energy Technology Handbook for Military Engineers.* 0.1 M	Methanol fuel for military applications; renewable energy options for remote sites; advanced military power systems. FY 1983 0.9 M
Agency for International Development (SEC, STM) (p. 98)	Renewable research laboratory development; resource assessment; technical support to AID. All prior year funding.	Scientific information exchange; field testing and research; technical support for international renewable energy cooperative research and development programs. 1.0 M
Department of Interior (STM) (p. 100)	Water desalination and power generation using solar ponds. 0.1 M	None proposed.

SEC = Solar Electric Conversion
SFC = Solar Fuels and Chemicals
STM = Solar Thermal and Materials
TIO = Technical Information Office

A. DOE PROGRAM EFFORT

This subsection presents the current programs and proposed new initiatives for the Assistant Secretary for Conservation and Renewable Energy and the Office of Energy Research. Current programs include those items in the interim AS/CE guidance as of August 5, 1981, and other ongoing programs expected to continue in FY 1982. New initiatives are offered to enhance these programs. New initiatives may appear incompatible with a reduced budget, but it is believed that those proposed would be timely, valuable, and cost-effective uses of public research and development funds.

1. CURRENT PROGRAMS

a. Assistant Secretary for Conservation and Renewable Energy (AS/CE)

The AS/CE subprogram at SERI for FY 1982 - FY 1987 consists of the following 10 program elements: photovoltaics, wind, alcohol fuels, biomass, energy storage, thermal, active, passive, and information.

The description of each program element includes a brief discussion of the potential of the solar resource being developed and the associated research needs, objectives and content of SERI's effort, future directions and major decisions, the value of planned accomplishments and a statement of SERI's role, and projected resource requirements.

Photovoltaics

Resource Potential and Research Needs

Photovoltaics has long been recognized as a potentially abundant source of clean, renewable electrical power. Photovoltaic systems require no complex machinery or moving parts; they are basically modular, and therefore adaptable to a variety of diverse applications. In 1980, approximately 30 companies were conducting research for the manufacture of photovoltaic systems; however, the total photovoltaic capacity sold that year was between 1 and 2 MW. With successful advanced research and development activities in the coming decades, it is conceivable that 10 to 100 GW would be the cumulative installed capacity by the year 2000.

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

The technical feasibility and reliability of photovoltaics has been a demonstrated fact for many years, and PV technology for specialized uses is relatively advanced. For example, PV solar cells have been used extensively to provide reliable power for satellites. However, the relatively high cost of PV systems have tended to confine terrestrial applications to small-scale, remote operations. For photovoltaics to augment the national electrical energy supply significantly, electricity would have to be produced at costs

reasonably competitive with electricity from other conventional generating sources. This requires research and development on materials and cells other than the crystalline silicon cells presently being manufactured and sold. Current research of this type consists of activities directed toward material alternatives, material/device processing, thin films, improved conversion efficiency, monolithic cell structures, scaleability of devices/processes, reliability, stability, and materials assessment.

The development of solar cells using new materials requires basic and supporting research to understand the generic properties of semiconductor materials, semiconductor devices, and fabrication processes, and their application to photovoltaics. Basic research encompasses those areas that address improvement of device performance without being associated with a specific device. These areas are general solid-state and device theory, experimental and theoretical work on surfaces and interfaces in the context of photovoltaics, and development of new measurement and characterization techniques. To provide greater understanding of the degradation mechanisms presently associated with some PV devices, a fundamental research is needed on the structural, chemical, and electrical properties of functional interfaces since they are often the limiting factors of PV device performance. Such a research program includes the study of semiconductor heterojunctions, Schottky barriers, interfacial atomic structures, metallization and encapsulation degradation mechanisms, and environmental effects upon cell efficiency.

As advanced cell technology progresses, appropriate new measurement technologies will become necessary in order to characterize and understand bulk thin-film materials, interfaces, and devices. Test and measurement facilities will be needed to provide the development of advanced measurement techniques and methods. Test facilities will also be required in order to provide verification of contracted research activities. As the lead center for Advanced Research and Development activities in photovoltaics, SERI intends to acquire and staff the additional quality facilities necessary to provide for these expanding needs.

Objectives and Content of SERI's Research

SERI's role for the FY 1982-1987 time frame will be to conduct high-risk, high-payoff research and development for the Photovoltaic Energy Technology Division's Advanced Research and Development (AR&D) subprogram. The objective is to advance scientific understanding and establish a technology base from which private enterprise may choose energy production options for further industrial development and introduction into the competitive market.

The AR&D subprogram will investigate newly evolving concepts, materials, and structures leading to very low-cost solar cells within the next decade (less than \$0.40/W_p array potential). Thin-film structures, in particular, offer material conservation, simplified film growth techniques, and the use of inexpensive substrates. To prove their technical feasibility, the AR&D program must demonstrate that these structures have a potential for adequate conversion efficiency while retaining attractively low material usage and high reliability. Higher conversion efficiencies are also being sought through advanced technology cells for use with concentrated sunlight. Because of their higher performance these cells can be more complex than cells used for flat-plate applications. Table II-2 presents a summary of the status and goals for the AR&D activities.

Table II-2. PV AR&D Status and Goals Summary Chart

Area	Status	Goals (for 3- to 5-year time frame)
Amorphous Materials	Amorphous silicon PIN cells of greater than 1-cm^2 area with greater than 6% efficiency developed. Deposition times for lower efficiency hydrogenated amorphous silicon cells reduced by factor of 5 in past year.	Identify barriers limiting present PV conversion efficiencies to 6%-8%. Develop material to extend efficiency above 10%.
Polycrystalline/Thin Films	9.93% efficient, small (Cd,Zn) S/$CuInSe_2$ cell produced; 8.3% 8-cm^2 cell; good stability 10.2% (Cd,Zn) S/Cu_2Se cell produced. 17% thin-film single crystal GaAs cells produced. One year exploratory development program in polycrystalline silicon has resulted in private initiation of a commercial venture. SERI discovery of edge-supported pulling transferred to industry.	Explore limits of conversion efficiency for thin-film polycrystalline solar cells. Determine and control long-term stability of cells through study of material physics. Develop understanding of chemistry/mechanism of grain boundary passivation.
Concentrator	Cascade cells with greater than 17% efficiency produced. Promising inorganic dye system identified for luminescent concentrators.	Conduct research that can lead to greater than 30% efficient multijunction concentrators. Explore luminescent concentrator to understand physical mechanism limiting conversion efficiencies of dye system.
Photoelectrochemical (PEC)	12.4% efficiency single crystal CdSe PEC cell produced. Greater than 5% efficient cells from less than 5 μm-thick films produced. Technique for enhancing cell stability by conducting polymer film discovered.	Better understand and thereby improve the conversion efficiency, stability, and storage potential of amorphous and polycrystalline semiconductor/electrolyte systems with a goal of developing a greater than 10% efficient cell with associated storage potential.

As the lead center for PV AR&D, SERI's responsibilities are to establish policies and conduct procedures for determining program structure and allocating resources, to develop PV AR&D program plans, to coordinate SERI program efforts with other aspects of the DOE PV program, and to perform other management activities as needed to maintain a productive research program responsive to the needs of the national photovoltaic community. In addition, SERI is continuing to build a laboratory of excellence in solid-state photovoltaic research.

In the amorphous silicon and other amorphous thin-film materials area, barriers presently limiting photovoltaic conversion efficiencies to 6%-7% are being identified, and techniques required to extend the efficiency to 10% or greater are being developed. Ongoing subcontract work will be selectively renewed in FY 1982, with emphasis toward the most promising preparation techniques (glow discharge, reactive sputtering, and chemical vapor deposition), studies of basic mechanisms, and alternate materials and technologies. An expanded program started in FY 1981 covering the glow discharge deposition technique will be continued. Technology support functions initiated at SERI will be continued and expanded. The support functions include studying RF glow discharge techniques, measuring hole diffusion length by the surface-photovoltage technique, and analyzing cell stability.

High-efficiency photovoltaic materials are being studied through subcontracted research and in-house support activities on high-efficiency or new polycrystalline silicon solar cells, thin-film gallium arsenide cells, high-efficiency concentrator solar cells, and luminescent solar collectors. The FY 1982 objective for the polycrystalline silicon area is to further investigate and develop two novel silicon sheet technologies (edge-supported pulling and low angle silicon sheet) to determine their potential. For the gallium arsenide area, the FY 1982 objectives are to achieve 9% efficient, large area, thin-film (less than 10 μ thickness) polycrystalline p/n junction cells; and to achieve 12% efficient, 1-cm^2 GaAs solar cells on germanium-coated silicon substrates. The FY 1982 objectives for the high-efficiency concentrator solar cells are to investigate metal-interconnected cascade solar cells with a goal of 25% efficiency, to investigate the mechanisms that control the performance of InP concentrator cells, and to improve metal-organic CVD for the growth of III-V compound cascade solar cells, especially with respect to the growth of the tunnel junctions. In the luminescent solar collector (LSC) area, the objectives are to synthesize and characterize stable organic dyes which exhibit appropriately large Stokes shifts, quantum yields, and solar absorption, and to study transition metal inorganic host materials suited for eventual development into efficient LSC systems.

Subcontracted research in the areas of cadmium sulfide/copper binary or ternary compound heterojunctions, emerging photovoltaic materials, and electrochemical photovoltaic cells is also being managed by SERI. In-house support research is carried out to assess and complement the subcontracted activities. The FY 1982 objectives for the cadmium sulfide area are to carry out research on thin films of Cu_2S- and $CuInSe_2$-based devices to obtain efficiencies of greater than 11%, and to determine and control the long-term stability of such cells. For the emerging materials area, the objectives are to investigate hot-wall vacuum evaporation and chemical vapor deposition of thin-film CdTe solar cells, and to understand the doping mechanisms for Zn_3P_2 and develop appropriate solar cell device structures. The objective of the electrochemical photovoltaic cell area is to achieve greater than 10% conversion efficiency and to demonstrate stability in polycrystalline or amorphous semiconductor/electrolyte systems having associated electrical energy storage potential.

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

Other support activities are conducted in insolation resource assessment (IRA). The FY 1982 IRA efforts will concentrate on improving spectral models and standards for terrestrial solar radiation at various atmospheric conditions; evaluating the SOLMET and ERSATZ historical data bases to determine their accuracy; measuring terrestrial solar spectral radiation for clear, cloudy, and urban conditions; evaluating and improving (goal of 5% absolute accuracy) algorithms to convert historical insolation data to tilted surfaces; and developing models, algorithms, and instrumentation to produce a time-integrated (day, month, year) terrestrial solar spectrum for various climates.

Future Direction and Major Decisions

In FY 1982, the AR&D effort is primarily applied research directed toward the investigation of new materials for solar cells. Applied research activities are expected to be predominant during the current planning period. However, basic research activities should increase in proportion to applied research. The basic research activities are those directed toward the generation of scientific understanding of solar cell materials and devices. It is expected that research activities would be carried only until private industry can reasonably be expected to continue the development of applied concepts.

Decision points within the PV AR&D activities will result from both the successful creation of an advanced technology capability within a company or the successful transfer of SERI knowledge and innovations to PV industries. In either case, the successes of the research efforts will be measured by the availability of developed technologies for further industrial pursuit and the selection of new high-risk, high-payoff research areas for future study.

Value of Accomplishments and SERI's Role

Successful accomplishment of this high-risk research will enable industry to develop and market technologies with the potential for electrical energy production. It will also help the United States maintain its leading status in PV technology development.

The present PV industry has a market limited by the high cost of its product. The future PV industry will be significantly larger given the development of cheaper and more efficient solar cells. The present single crystalline silicon technologies appear unable to achieve the required low cost.

SERI's unique scientific competence in both in-house research and technical management of subcontracted research efforts is vital to the successful execution of advanced research and development in PV. SERI's PV researchers published extensively during FY 1981 in both refereed professional journals and technical conferences. Further, SERI's early effort to build a laboratory of excellence in photovoltaic research has resulted in an impressive functional inventory of advanced laboratory research equipment used for both SERI research activities and as research support of subcontracted activities. These capabilities include equipment and procedures for conducting cell standardization techniques, interface studies, material and device characterization including spectral response studies, and other highly specialized techniques essential for high quality PV research. SERI's research and device and materials assessment capabilities are now recognized as a unique and independent assessment resource that is not possessed by any single PV firm or university. For example, SERI evaluated over 280 solar cells for DOE contractors and SERI researchers in FY 1981.

Resource Requirements

It is estimated that funding for this activity will approximate $16 million annually for the duration of the planning period. The activity will employ between approximately 101 and 116 people.

New Initiatives

New initiatives are being proposed to strengthen research in the following areas: basic research, innovative concepts, material properties and module degradation, and insolation resource assessment. Details regarding the need for these additional activities are contained in Sec. II-A (2a).

Wind

Resource Potential and Research Needs

Wind energy has long been recognized as a potentially abundant source of clean mechanical and electrical power. In the early 1970s, the impending worldwide shortage of nonrenewable energy sources and the nation's increasing dependence on imported fossil fuels led to an expanded investigation of the feasibility of converting wind into useful energy. During the ensuing years, numerous studies have established that wind energy has the potential to be one of the first of the renewable energy options to be cost-effective and capable of producing significant amounts of electric power, both in central utility applications and in distributed applications. Estimates have been made that wind energy could account for over one quad of total U.S. energy needs by the year 2000. This potential also is underscored by the increasing numbers of small wind machine manufacturers and large machine developers, as well as by the rapidly increasing utility interest in wind energy development.

In view of these trends, the Federal Wind Energy Program emphasizes high-risk, potentially high-payoff research and support of the wind energy industry technology base. In keeping with this emphasis, the SERI Wind Energy Program conducts research to identify higher efficiency wind energy devices or components and develops methodologies to determine the causes and extent of technical and environmental problems associated with large wind turbines, with the aim of minimizing or eliminating identified problems.

Objectives and Contents of SERI's Research

The overall objective of the SERI Wind Energy Program is to support the widespread implementation of wind energy technology by conducting research and development in three major areas: advanced and innovative wind energy concepts, noise research, and supporting research.

Determining the technical feasibility of advanced and innovative wind systems is the purpose of one group of in-house and subcontract research and development studies. These task efforts begin with theoretical examination of the physical principles and end with critical evaluation of the concept. This is accomplished by identifying and supporting R&D and assessment studies of concepts that have a potential of being more cost-effective than current wind energy systems, supporting concepts that will improve system cost-competitiveness, and providing wind tunnel evaluation and verification of selected concept performance. The effort will also produce standard costing and evaluation methods so that the development, preproduction, and product costs of an advanced concept can be determined during its conceptual and early development phases. The effort will provide aerodynamic and engineering analyses of specific concepts to predict their structural performance and material characteristics. Cost and performance assessments are then conducted to identify advanced and innovative concepts that have the potential of advancing to the proof-of-concept phase.

In the area of noise and related research, SERI activities include measurement and analysis of the principal wind turbine noise-generating mechanisms and development of improved television interference prediction techniques for wind turbines in various terrain. Additional investigations include the evaluation of wind system operational characteristics of importance to value analysis planners of electrical utilities. The work will be accomplished by investigation of the principal wind turbine noise-generating

mechanisms and their relationship to machine design parameters and operating environments, development of methods for the quantitative assessment of the annoyance levels of existing and new turbine designs, development of methods to quantify the levels of interference found in specific telecommuncations systems; and investigation of technical and cost characteristics of wind system/storage combinations.

In the supporting research area, the SERI-developed wind energy conversion systems (WECS) computer models will be updated in FY 1982 to account for discrepancies between the model predictions and actual operating data. Also, several utilities with the addition of wind energy systems will be modeled to further investigate factors that may increase the value of WECS to utilities.

The SERI Wind Energy Program is also conducting several studies required under the Wind Energy Systems Act of 1980. For example, one study seeks to determine the potential of wind energy systems at federal facilities. The preliminary analysis indicates that about 1,300 of the 9,000 sites that were considered, representing about 800 MW of capacity, are potentially economically competitive. SERI also examined the prospects for foreign applications and export potential for U.S.-manufactured wind energy systems. This preliminary study is worldwide and identifies countries that have applications for which wind energy is competitive with conventional energy sources and that do not have excessive barriers to U.S. exports.

Future Direction and Major Decisions

In the area of advanced and innovative wind systems, advanced WECS for urban use appear to have merit. Several of these concepts will be identified and assessed through a competitive procurement. The diffuser augmented wind turbine, the electrofluid dynamic wind-driven generator, and the dynamic inducer require further investigation of selected areas of concern. These are to be accomplished by the award of follow-on efforts. Wind tunnel and controlled velocity testing of advanced concepts are essential to the evaluation of their cost-competitiveness. The capability for these tests will be developed, and selected designs will be tested.

In the area of noise research, the isolation of the principal WECS noise-generating mechanisms and their relationship to machine design parameters and operating environments will be examined. SERI will establish specific characteristics of WECS noise that are undesirable and their correlation with the responsible noise generation, propagation, and impact mechanisms. A methodology for the quantitative assessment of the annoyance potential of existing and new WECS designs will be developed. Codifying will be undertaken, as much as practical, of the source-path-receiver sequence for prediction of annoyance potential for specific WECS designs and installations. SERI will identify effective, ameliorating techniques through initial design or by retrofit. Finally, appropriate siting guidelines for minimizing the annoyance potential from any infrequent or residual noise sources will be established.

Value of Accomplishments and SERI's Role

The value of SERI's accomplishments will be in discovery and support of viable wind energy systems or components that wind turbine manufacturers could not be expected to evaluate or support on their own initiative. SERI's assessment capabilities have been established as the result of the evaluation of hundreds of innovative wind system concepts since 1978, the technical management of dozens of advanced and innovative wind

system subcontracts, and the convening of two innovative wind system conferences that attracted researchers from around the world.

Under SERI's management, several advanced and innovative wind energy concepts are beginning to show promise. For example, the dynamic inducer tip vane proposed by Van Holten of the Delft Institute of Technology has been studied for two years by AeroVironment under a SERI subcontract. The dynamic inducer is intended to augment the power of the horizontal-axis wind turbine by inducing a greater mass flow through the rotor disk. Wind tunnel and field measurement tests have indicated a possible 70% increase in rotor power coefficient with tip vanes. Also, cyclic pitch control studied by Professor Hohenemser of Washington University Technology Associates offers interesting possibilities for reducing both the complexity and the dynamic stresses on the rotor and nacelle of a horizontal-axis wind turbine. The control system also allows overspeed control to be obtained by yawing the rotor rather than by feathering its blades.

In the noise research area, SERI researchers have identified and partially resolved the specialized infrasound (noise) problem arising at wind turbine sites.

Resource Requirements

It is estimated that funding for this activity will vary between $1.55 million and $2.0 million annually for the duration of the planning period. The activity will employ approximately 18 people.

New Initiatives

No new initiatives are proposed at this time; however, SERI will seek to expand its current work based on existing research strengths and headquarters guidance.

Alcohol Fuels

Resource Potential and Research Needs

Transportation fuel is a major energy concern for the future. Alcohol fuels could play a significant role in meeting the United States' transportation fuel needs. They can be produced from a variety of resources, both renewable and fossil.

Fuel alcohol provides distinct technical advantages as a blending agent and a neat fuel over gasoline or diesel fuel. As a synfuel, alcohol can be produced 15%-20% more efficiently than synthetic gasoline. By modifying the conventional gasoline engine, alcohol fuels can be burned with significantly higher efficiencies than gasoline per unit of energy content. For example, with simple engine modifications a 30%-40% fuel efficiency improvement is possible; by dissociating alcohols 50%-90% improvements are possible; and advanced systems show promise for 100%-140% improvements. By comparison, today's diesel engine is only 10%-15% more fuel efficient than a conventional gasoline engine.

Renewables could provide a major portion of the nation's fuel requirements. Competitive processes to produce methanol, ethanol, and other fuel alcohols and high efficiency utilization systems are needed to make alcohol from renewables a competitive option. There are many research needs and opportunities for meeting these objectives.

Objectives and Content of SERI's Research

SERI's FY 1982 Alcohol Fuels research activity is divided into two primary areas: alcohol production process research and alcohol utilization research. Production process research examines effective methods for obtaining alcohols from cellulosic materials, the most readily available and least expensive renewable biomass resource. Biological processes are being explored to convert cellulose and related compounds to sugars that can readily be fermented to ethanol. Thermal processes are being investigated to produce syngas suitable for catalytic conversion to methanol. Utilization research is undertaken to explore more efficient methods for using alcohol fuels, thus increasing their value. The activities are performed both internally at SERI and through SERI-managed subcontracts.

Alcohol Production Process Research

Alcohol production process research includes the following activities:

Alcohol Fuels Research Management. The objective of the research management task is to fund high-risk research on concepts that convert cellulosic and lignocellulosic materials to alcohols via fermentation or gasification and that provide a technology base which will encourage the private sector to develop alcohol fuels processes to commercial scale. The concepts studied are those with significant potential to displace conventional liquid fuels on a cost-benefit basis. The program is achieved through identification of the key technical and cost sensitive process areas, with most research then subcontracted to appropriate institutions for resolution.

Process Research for Ethanol. The objective of the process research element is to improve current cellulose-to-alcohol biotechnology processes and to initiate research programs leading to second and third generation cellulose-to-alcohol systems. The process research area is focused on ethanol production through three approaches, namely acid hydrolysis kinetics, medium-temperature enzymatic hydrolysis, and high-temperature enzymatic hydrolysis.

The acid hydrolysis research strives to obtain basic kinetic data on hydrolysis, which can be used to evaluate new process concepts.

The medium-temperature enzymatic hydrolysis research concentrates on the identification, selection, and improvement of organisms capable of hydrolyzing woody biomass directly to sugars fermentable to ethanol. The potent, cellulose-producing organism, RUT-C30, is being studied to develop and define the growth media and conditions that optimize cellulose production. The fungus Fusarium sp., which converts the C5 and C6 portions of woody biomass to ethanol, has been isolated and is now being characterized. This work is important since it has the potential to circumvent the costly pretreatment step normally associated with enzymatic processes.

The high-temperature enzymatic hydrolysis research may provide increased hydrolytic reaction rates and a potential for direct linkage with a vacuum distillation system. Both hydrolysis options offer savings in process costs. Research is underway to develop a mixed thermophilic bacteria culture process for converting the cellulose and hemicellulose of corn stover directly to ethanol. This could improve ethanol yield by 20%-30%. Work is also being done to improve the thermal tolerance of fermentative mesophilic bacteria through gene splicing so that associated reaction rates may be greatly increased.

Process Research for Methanol. The objectives of this research are to build and demonstrate a gasifier specifically designed to generate syngas suitable for conversion to methanol, and to evaluate catalytic approaches for converting syngas to methanol, other liquid fuels, and chemicals. An oxygen gasifier has been constructed, tested with biomass at atmospheric pressures for syngas production, and the resulting syngas converted to methanol through an existing process. Data on biomass gasification at high pressure will be obtained, and the effects of feedstock size and composition will be explored. Steam addition, ash content, and temperature distribution will also be studied.

New and novel dinuclear transition metal complexes for the catalytic activation of H_2 and CO have been prepared and will be characterized. This will provide the basis for the further design and development of these new and unique kinds of catalytic systems. A crucial review of the more traditional area of methanol synthesis and catalysis will be completed. The evaluation of new heterogeneous methanol synthesis and methanol dissociation catalysts will be done in the context of these studies and will represent the beginning of a joint SERI/Colorado School of Mines collaboration in this area. A complete heterogeneous catalysis laboratory is being established.

Support Research. The support research element of the program concentrates on process improvements and cost reductions in the areas of separation of alcohol and water, pretreatments, and by-product utilization.

The separation of ethanol from dilute water solutions to produce fuel-grade alcohol with present distillation technology is a capital- and energy-intensive process. A competitive solicitation was issued by SERI in FY 1981 for novel energy-conserving ethanol/water separation processes. Continued support will be provided for novel technologies offering energy- and cost-saving approaches. A mid-year review will attempt to identify candidate processes with real potential for future funding and development.

Pretreatment processes being investigated are steam explosion, wet oxidation, and solvent delignification. Each of these processes offers a method for disrupting the chemically and physically resistant lignocellulose structure.

The utilization of by-products from cellulose-to-ethanol conversion processes produces added revenues and is seen as one of the keys to economic viability of cellulose-to-ethanol plants. The principal by-products are CO_2, xylose, xylose degradation products, and lignin. Since there is a ready market for CO_2 in large quantities, this area has not been considered in the program. Xylose is proposed to be used in several processes, i.e., to make xylose syrups as a molasses substitute in animal feed, and to make ethanol and/or butanediol as fuel additives.

Process Evaluation. Process evaluations are conducted to provide technical support and evaluation functions for alcohol fuels research, including engineering evaluations and critical analyses on process flow sheets for candidate processes. These will provide valuable information regarding the viability of processes and guidelines or direction for future process improvements.

A computerized model of enzymatic hydrolysis will be completed and tested during FY 1982. Coupled with the acid hydrolysis model already constructed, these tools should provide a methodology for identifying cost sensitive areas in these processes. This approach will help establish priority areas in the current program for further funding and identify missing or underfunded areas in the program to be filled by solicitation. These analyses will also provide a framework for establishing process cost goals and programmatic technical objectives.

Alcohol Utilization Research

Alcohol utilization research examines prospects for developing highly efficient engines able to use alcohol fuels, and investigates electrolytes for direct methanol fuel cells. The specific objectives and content of activities within these two areas are:

Advanced Engine Research. The general objective of this research is to investigate very high-efficiency alcohol utilization systems in order to increase the value of alcohol as a fuel. The specific objectives of this year's effort are to conduct proof-of-concept experiments to assess the feasibility of dissociated ethanol/methanol automobiles and a dissociated alcohol gas turbine. Preliminary work will be initiated on multifuel engines and fuel cell hybrid vehicles to define state-of-the-art research opportunities.

Alcohol (methanol and ethanol) will endothermically dissociate into hydrogen and carbon monoxide. If waste engine heat is used to provide heat for the reaction and the engine modified to take full advantage of the hydrogen fuel, substantial efficiency improvements result. Vehicle work currently being done at SERI will

continue into FY 1983 with emphasis on dissociated ethanol and dissociated methanol operating fuels. Work on combustion turbines fueled with dissociated alcohol will begin in FY 1982 for a variety of applications including both transportation vehicles and electricity generation.

Advanced Methanol Fuel Cell Research. The objective of this research is to investigate alternative electrolytes for direct methanol fuel cells at various temperatures. A survey of electrolytes will be prepared. Selected electrolytes will be tested for direct and indirect fuel cell use. A workshop will be organized to discuss the area of fuel cells for transportation.

Fuel cells are efficient electrochemical devices converting chemical energy into electrical energy. Consequently, these devices are not Carnot cycle limited and efficiencies as high as 90% of the theoretical are possible. Hydrogen and oxygen fuel cells can be operated with a variety of electrolytes: acid, alkaline, superacid, molten salts, solid, etc. Whereas several of these media have been investigated, mainly for stationary power operation, the vehicular application has not received the research attention justified by the large overall efficiencies that these systems can have compared to internal combustion engines. SERI has a unique combination of skills that can be applied to this research.

Future Directions and Major Decisions

A continuing Technical Evaluation and Planning effort (TEP) reviews the progress of current research and identifies opportunities for the future. At present SERI's, efforts in wood to methanol, cellulose to ethanol, and high-efficiency alcohol utilization are well oriented. Dramatic results are anticipated in each area. Even with such success, major research opportunities remain.

Improvements in SERI's wood to methanol technology are possible. Increasing operating pressure, the use of wood and methane-mixed feedstock or the use of supplemental hydrogen could have significant impact. A number of research opportunities are associated with these improvements. Feedstocks other than wood and technology other than oxygen gasification should be considered. Thermal gasification is only appropriate for moderately dry, low-ash feedstocks. Wet feedstocks may be readily converted to biogas, a mixture of methane and carbon dioxide. Several novel concepts involving thermochemistry, electrochemistry, or photoconversion will be investigated for converting biogas to fuel alcohol.

Biotechnology research on the conversion of cellulose to fuel alcohol and on coproducts offers a framework for a wide range of exploratory research. Opportunity areas include: syngas fermentation; microbiology of thermophiles, yeasts, and algae; immobilized cell fermentations; enzyme systems and catalysis; separation science; and biochemical engineering research. This general area of high-risk, high-payoff research is one of the most promising today.

High-efficiency utilization is another key area. Fuel alcohols have distinct advantages over hydrocarbon fuels, if technology is developed to capitalize on them. Alcohols are more reactive chemically and at lower temperatures than hydrocarbons. This allows a rather easy conversion, on small scale, to hydrogen. This in turn allows a variety of very efficient options for utilization. The SERI dissociated methanol, automotive engine project is but the first of a series of opportunities to apply this concept. Perhaps the

ultimate in high fuel efficiency will be obtained through the use of fuel cells. There are numerous cutting edge opportunities in this field. Because of SERI's interdisciplinary skills in surface chemistry, electrochemistry, advanced catalysis, electrolyte-semiconductor interactions and related sciences, SERI is well qualified to make major contributions in this field.

Such opportunities and others are now being explored to identify specific projects to be addressed by future research efforts. There is no question that suitable, high-risk projects exist that are appropriate for federal funding.

Value of Accomplishments and SERI's Role

SERI's program has been very productive and promises to make significant future contributions. SERI has developed an oxygen pressurized gasifier for wood. This is the key component of a wood to methanol process. Future improvements might double the yield based upon wood feedstock. Substantial improvements have been made in wood hydrolysis and fermentation. SERI's Biotechnology capability can contribute significantly. SERI has pioneered the development of a very fuel-efficient, dissociated methanol automotive system. Looking to the future, SERI is now scoping a significant research effort in the area of alcohol fuel cell electric hybrid systems. SERI has the necessary capability in electrochemistry, surface catalysis, single carbon chemistry, materials, and other disciplines to make major contributions in fuel cell technology.

The long-range benefits to be derived from SERI's Alcohol Fuels Program will result from SERI's ability to carefully focus research in order to achieve the most marked improvements at conservative research costs. Methanol may be produced from wood through gasification within the next three to five years, with ethanol fermentation processes perhaps becoming cost-competitive within the next five to ten years. Engine and power systems for efficient alcohol fuel utilization are also projected to be commercialized at rates corresponding to alcohol fuels availability.

A successful research program will lead to the displacement of petroleum fuels coupled with the widespread use of renewable liquid fuels. The development of low-cost alcohol production systems and high-efficiency utilization systems will allow alcohol fuels to compete in markets without subsidy. SERI has a leading role in the research, technology, process analyses, and assessments for alcohol fuels production processes and alcohol fuels use. SERI performs and manages research for the DOE Office of Alcohol Fuels to support the timely development of alcohol fuels production and utilization technologies. SERI employs a unique multidisciplinary staff with the experience, interest, and ideas required to carry out the vigorous, goal-oriented activities needed for success. In addition, a great deal of specialized research equipment has been installed in the SERI laboratories. Both industry and universities participate in this program; however, there is no evidence that industry is yet prepared to proceed on its own with the high-risk research needed to reach the stated objectives.

Resource Requirements

It is estimated that funding for this activity will vary between $8.0 million and $10.0 million annually for the duration of the planning period. The activity will employ between approximately 50 and 68 people.

New Initiatives

No new initiatives are presently proposed for this area.

Biomass

Resource Potential and Research Needs

Most products derived from petroleum can be produced directly from biomass. For example, as much as 90% of the organic cell weight of certain microalgal species can be oils, either as hydrocarbons or as mono-, di-, and triglycerides; particular emergent plants can synthesize fermentable sugars at levels exceeding 60% of the total plant weight; and the lignocellulose polymers of woody species and crop residues can be converted to higher value chemicals or fuels. The challenge, however, is to develop technology which will produce these products competitively. This challenge provides several important opportunities for high-risk, high-payoff research in biomass production and conversion technologies.

Biomass production can be substantially improved. For example, present data indicate that 100-200 bbl/acre of high-quality, medium-weight oil may be obtained annually from microalgae grown on Southwestern desert lands using saline water. Analyses further suggest that upwards to 135,000 mi^2 (86.4 million acres) of desert surface land might be suitable for this purpose. If true, only a fraction of this land area would be required to replace a substantial amount of petroleum-based products using oils derived from microalgae. Other biomass sources include crop residues, noncommercial forest species, and wastes.

The basic and exploratory research opportunities in biomass conversion are substantial. Some present studies include: fast pyrolysis of wood to olefins, photobiological conversion of organic wastes to hydrogen, high-yield anaerobic digestion of wastes, electrochemical conversion, and thermophilic fermentations.

Conversion methods are varied and include simple fractionation, extraction, thermochemical (pyrolysis, gasification, etc.), biochemical (fermentation, enzymatic reactions, etc.), electrochemical, and catalytic. Due to the highly oxidized state of most biomass, reductive methods are particularly interesting. Therefore, an attractive synergism exists between biomass conversion and solar hydrogen research.

In aggregate, biomass resources could displace at least 10 quads of petroleum energy by the year 2010. An ultimate potential several times this figure has been projected. However, economical methods for producing or collecting biomass and converting it to high value fuels and petrochemical replacements must be developed. Technologies which capitalize on biomass' unique structure will be competitive with fossil resources. Virtually any product now produced from fossil energy resources could be produced from biomass.

Objectives and Content of SERI's Research

The central objective of SERI's biomass research is to establish the requisite technology base from which economic biomass-based fuel and chemical processes may be developed. Analyses are conducted to identify research opportunities and goals, to assess program progress, and to establish priorities.

SERI has been delegated overall field management responsibility for three program areas within the DOE Biomass Energy Technology Division (DOE/BET); specifically, the Anaerobic Digestion, Aquatic Species, and Photobiological Hydrogen Programs. The SERI Fuels and Chemicals Division fulfills this responsibility through coordination of in-house and subcontracted R&D, including technical and economic evaluations, systems analysis, and program planning. The Division also conducts research in thermochemical and electrochemical conversion of biomass, as well as basic and applied photobiology R&D for hydrogen production, nitrogen fixation by microorganisms, and for the production of oils from microalgae and bacteria. The specific objectives and content of activities within each area of the SERI Biomass Program are as follows:

Aquatic Species Program. The Aquatic Species Program objective is to investigate a variety of practical systems options for providing renewable petroleum replacement products that are suitable for commercial and venture groups to pursue to commercialization. Current emphasis is on the exploration of technologies that employ microalgae capable of producing oils directly, and emergent aquatic plants (e.g., cattails and reeds) as feedstocks for conversion to gaseous, liquid, and solid fuels and chemicals.

Anaerobic Digestion Program. The Anaerobic Digestion Program objective is to investigate conversion options, based upon the anaerobic digestion of biomass feedstocks to methane gas, which meet with the economic and applications requirements of potential commercial user groups. Major current thrusts include studying the pretreatment of feedstocks required to enhance digestibility and yields, investigating simple but efficient digestion reactors, establishing the performance of prototype and full-scale digesters, and identifying organisms and conditions for improved digester performance. Feedstocks being considered include manures, crop residues, and biomass materials within process waste streams.

Photobiological Hydrogen Program. The Photobiological Hydrogen Program objectives are to investigate options for producing hydrogen from autotrophic microorganisms for the purpose of upgrading the quality of products obtained from various conversion processes and to examine processes for converting biomass to hydrogen through direct replacement with inert gases. Subcontract efforts currently focus on selecting and improving upon the hydrogen production efficiency obtained from photosynthetic microorganisms, identifying appropriate substrates for microorganism growth, and establishing the feasibility for cyclic displacements of hydrogen fixed in the organic components of biomass materials.

In-house research concentrates on defining the basic mechanisms involved in photobiological hydrogen production as well as defining the fundamental parameter requirements for maximizing photobiological hydrogen production in laboratory and bench-scale outdoor reactors.

Thermochemical/Electrochemical Conversion Research. These in-house research activities have the common objective of investigating novel system components dedicated to the conversion and upgrading of biomass feedstock materials to fuels and essential chemicals. Thermochemical research focuses on the basic mechanisms and design of gasifiers and pyrolytic reactors to better understand reaction kinetics and sequences, as well as to advance reactor knowledge for the thermochemical conversion of biomass feedstocks. Electrochemical research emphasizes the advancement of technologies for upgrading biomass-derived compounds to essential petrochemical substitutes. The electrochemistry of lignin materials is being

investigated fully, leading to the synthesis of low-molecular-weight phenolic compounds and an improved understanding of the structure, reactivity, and redox properties of lignin materials.

Future Directions and Major Decisions

The long-range goal of the SERI Biomass Program is to identify and to research innovative biomass energy systems that have significant potential for meeting continued national requirements for fuels and chemicals. Recognizing the high risks associated with the development of such options, the program has elected to pursue a dynamic strategy that can respond to projected fluctuations in product supplies, market demands, national needs, and new technical developments. Close associations and coordinated activities are established and maintained with industry, other research organizations, and governmental agencies to obtain the information needed to guide SERI's biomass research program and to encourage timely transfer of research results to the private sector.

Analyses performed to date have indicated substantial advantages to biomass energy systems conceived to operate in underutilized areas, such as arid lands, marginal lands, and wetlands, to utilize saline or otherwise nonpotable waters, and to have beneficial impacts on environmental resources. These factors eliminate or minimize land-use conflicts, competition for water, and difficulties in environmental degradation that could adversely influence the long-term operations of the systems. Each of the biomass program areas managed by SERI is carefully focused to incorporate these factors, and make major improvements in the production and conversion of biomass feedstocks into useful fuels and essential chemicals.

Major decisions will need to be made as requirements are better defined for technical developments and sustained systems operations. In order for aquatic species, particularly microalgae, to produce oils, certain physical and chemical requirements must be met, including land, water, salts, nutrients, carbon dioxide, and sunlight. While it appears this can be achieved using arid lands that overlay shallow saline groundwater reservoirs, field studies must be conducted to verify this potential. Algal species, capable of growing and producing oils from these water supplies, need to be identified, characterized for product potentials, and selected. Appropriate systems must be technically feasible for algal mass culture. Each of these research areas is essential to the success of the program and will constitute major determining factors over the next five years.

Anaerobic digestion technologies have advanced to a point where they are marginally cost-effective today. Improved understanding of the biochemistry and microbiology of the processes, along with innovative reactor design, offers additional technical and economic improvements. Basic understanding of these areas must be obtained before the benefits offered by this technology can be realized throughout the United States. The program will also contribute to the development of technologies for upgrading crude biomass to petrochemical substitutes and liquid fuels. Major decisions on research direction will be made based on performance successes in these areas over the next three years.

Similar decisions must be made in the Photobiological Hydrogen Program. Identifying and/or developing suitable hydrogen-producing microorganisms, developing prototype systems and materials for mass hydrogen production, and developing methods to locate sites having the essential resources for sustained process operations, will be major considerations addressed by the program through the year 1989.

Innovative concepts using state-of-the-art advances in biotechnology, electrochemistry, and photoconversion will be sought and incorporated into the program as appropriate.

Value of Accomplishments and SERI's Role

The aquatics activity is a balanced effort of in-house research and subcontracted projects. SERI researchers have developed rapid screening methods to identify potential oil-producing algae. To date, 12 strains have been identified and the biochemistry of three has been studied. SERI has constructed and now operates a unique, nanosecond, laser spectrometer to study the basic photon-chlorophyll interaction. Significant results on photon-induced charge separation and activated state degradation have been obtained. This and other basic research should lead to an understanding of the factors controlling photosynthetic efficiency and stimulation of oil production. Algae are among the most photosynthetically efficient organisms.

Through a combined subcontract and SERI effort, an experimental system has demonstrated that mass culture productivities of 100-200 bbl/acre-yr are feasible. Present and planned research will establish an understanding of the principles involved that control oil production and optimize yield. When feasible, microalgal culture will permit the use of currently unproductive land and unused saline or brackish water resources to produce fuel, chemicals, and feed.

The anaerobic digestion activity has developed an efficient culture for converting crop residues to biogas. Previous systems recovered less than 50% of the residue energy; the new system recovers 70%. A number of low-cost digester design concepts have been considered. The bacterial culture involved in anaerobic digestion is extremely complicated. Improved understanding of the microbiology of this mixture is likely to provide opportunities not presently identifiable. For example, an organism has been identified that can convert synthesis gas to products.

Biological hydrogen production promises to both produce a valuable commodity (hydrogen) and provide a very efficient waste treatment process. SERI has developed the largest collection of photosynthetic bacteria in the world. Several of these organisms can be used for photobiological hydrogen production. Through related research, SERI has isolated photoreaction centers and immobilized them on electrodes. This technique will allow further study of the photosynthetic process and may allow useful organic photochemistry outside of the living cell.

SERI has established a technical leadership role in certain aspects of thermochemical conversion of biomass. The Survey of Biomass Gasification produced by SERI is used as a text in some universities. SERI is conducting key research in the mechanisms of biomass thermochemistry. International workshops in fast pyrolysis and biomass electrochemistry have stimulated research. SERI's fast pyrolysis research is directed toward production of olefins from wood; our oxygen gasification work will lead to a commercial process in the near future. Thermochemistry of biomass is a promising conversion method; SERI's research efforts will be contributing significantly to the necessary technology base.

SERI has surveyed biomass production and conversion technology and identified areas of opportunity for basic research and applied science and engineering. This combination of basic research capability and vision toward applications drives the creative process. Continued results toward establishing biomass as a credible energy alternative can be fully expected.

Resource Requirements

Funding for this activity will be approximately $5.9 million annually for the duration of the planning period. The activity will employ between approximately 34 and 37 people.

New Initiatives

New initiatives are being proposed in several related areas [See Sec. II-A (2a)].

Energy Storage

Resource Potential and Research Needs

The storage of solar energy is essential if solar technologies are to meet the demand of consistent energy output required at night or during periods of limited solar radiation. For instance, the maximum solar energy availability occurs during the middle of the day contrary to heating requirements that generally reach a maximum during the night or early morning. Reliable energy storage compensates for this inconsistency by extending solar applications to loads which are not coincident with solar radiation availability and consequently is vital if solar energy is to meet a large fraction of total U.S. energy needs.

By the year 2000, about one third of a quad of solar thermal electricity production could be furnished through thermal storage. Ultimately, both advanced thermal energy storage and solar thermal power technologies will come into the marketplace. A major portion of the total U.S. energy demand is for either electric power or process heat and as much as 60% of the solar thermal energy supplied to these markets could advantageously use storage. In addition, thermal storage technologies are expected to be instrumental in the production of solar-derived fuels and chemicals in the next several decades.

Present storage systems tend to be cumbersome, expensive, and typically operate at less than desirable efficiencies. A sustained research effort is needed to build up the technical base of storage technology and to make suitable technologies that facilitate widespread use of solar energy. Needed research activities include: the development of cheaper, more efficient storage materials and containing vessels; the advancement of more effective thermal energy storage and transport technologies for solar thermal power and process heat applications; research on transport of thermal energy for a full range of applications; and identification of promising research projects through analyses and assessments. Major improvements are needed in high-temperature, long-duration storage, long distance transport of high-temperature thermal energy, and in the cost of heat transfer and exchange.

Objectives and Content of SERI's Research

SERI is the lead laboratory for research, technology and systems analyses, and assessments for thermal storage applied to solar thermal applications and for thermal energy transport. This effort supports the Thermal Energy Storage Program of DOE's Division of Energy Storage Technology and the joint Thermal Energy Storage for Solar Thermal Applications (TESSTA) Program between DOE's Divisions of Energy Storage Technology and Solar Thermal Energy Systems.

The objective of SERI's program is to conduct research in advanced thermal energy storage for solar thermal power and process heat applications, and transport technologies for a wide range of end-uses. As part of the program, data and information will be obtained that will allow developers to select cost-effective thermal energy storage and transport technologies for identified applications. As a result, a technology base will be provided that will allow the private sector to develop low-cost storage systems.

Current research areas include storage systems that use direct contact heat exchange. Salt hydrate systems are being studied first since their moderate fusion temperatures will simplify experimental design, and these materials have already received attention for their storage capabilities for home heating and cooling. The potential of such low-temperature direct contact systems will be evaluated. Subsequently, high-temperature direct contact heat exchange between gases and liquids will be studied to determine whether research is warranted.

Research will continue in FY 1982 to complete the feasibility study of thermochemical energy storage and transport (TEST). Appropriate program guidance recommendations on whether TEST is promising will be made to DOE, and areas where additional laboratory research is required will be indicated. The reversible chemical reactions under consideration include CO_2 and H_20 reforming of CH_4, dehydration of $Ca(OH)_2$, and dissociation of SO_3. The studies will center on determining reaction kinetics, mechanisms, side reactions, heat and mass transfer effects, and the effects of reactor geometry. Results will be applicable to either energy storage or transport.

A systems analysis activity in the SERI Solar Energy Storage Program provides criteria for selection of thermal energy storage concepts for solar thermal application and identifies key research issues. Based on these studies, promising thermal storage systems are selected for further research. New concept definition research provides experimental and analytical evaluations of innovative approaches to storing high- temperature thermal energy.

Future Directions and Major Decisions

As in all research programs, future efforts in the storage program will depend on the results of current research projects. A decision will be reached in FY 1982 on gas-liquid direct contact heat exchangers for solar thermal applications and on promising thermal storage concepts for liquid metal receivers. Decisions will be made on all concepts with potential for meeting the cost and performance goals. SERI will provide a technical evaluation of high-temperature, liquid-solid, direct contact latent heat storage for power plant applications, based on research in industry and at SERI. A study will be completed of the most promising thermochemical energy storage and transport systems and a decision will be made as to whether the technology is sufficiently promising to warrant laboratory demonstration and characterizations. When funding warrants, a new thermal storage idea relying on a unique thermocline separation will be investigated.

Value of Accomplishments and SERI's Role

Cost goals have been established for thermal storage in solar thermal power and process heat applications and competing technologies have been compared. Based on the initial results, significant improvements are needed in thermal energy storage for high-temperature solar thermal power and for process heat uses. In addition, a need has been identified for major improvements in high-temperature, long-duration storage, long distance transport of high-quality thermal energy, and in the cost of heat exchange. Each of the technologies being pursued in the advanced thermal energy research project portion specifically addresses these issues and has the promise to offer cost and performance improvements of about 25% or more. Achievement of these goals would significantly improve the potential of thermal energy storage and transport and establish a technology base with sufficient economic potential that the private sector would likely undertake a large-scale demonstration and development of the technology.

The advanced thermal energy storage portion of the project is intended to support solar thermal power and process heat users. Thus, an improved technology base will be provided for solar thermal electric power generation and solar thermal process heat uses. The advanced thermal storage technologies will also have use of off-peak electricity storage as heat and for high-temperature waste heat use.

SERI staff has the required expertise and resources to conduct the research, system analyses, and assessments that are necessary to accomplish this role. SERI conducts research in important areas, such as direct contact heat exchange for thermal energy storage, and thermochemical energy and transport, that will provide a technology base on critical aspects of storage. SERI also has systems analysis capabilities that provide decision-making guidance for SERI, DOE, other national laboratories, and subcontractors. The SERI staff manages subcontracts on storage research and provides guidance to the subcontractors on critical research areas and system issues to be investigated. The main impediment to the private sector undertaking this research is the high technical and economic risk associated with the advanced technologies being investigated.

A sufficient technology base does not currently exist to determine if thermal energy storage can fulfill the expected economic role that would encourage the private sector to develop the technologies for commercialization. The definitive results to be provided through this research at SERI will form a sound basis for private enterprise to evaluate the technology, determine the market potential, and commercialize systems.

Resource Requirements

It is estimated that funding for this activity will vary between $1.05 million and $1.6 million annually for the duration of the planning period. The activity will employ between approximately 14 and 19 people.

New Initiatives

A new initiative relating to thermally regenerative electrochemical systems and electrochemistry is included in Section II-A (2a), New Initiatives, Conservation and Renewable Energy.

Thermal

Resource Potential and Research Needs

Solar thermal energy systems are fundamentally heat sources, converting solar radiation to thermal energy. They are unique among the various solar technologies in four ways. First, they can meet the requirements of all energy markets, providing both thermal and electrical energy at almost any scale from a few tens of kilowatts up to hundreds of megawatts, as well as producing transportable fuels and chemical feedstocks. Second, solar thermal energy systems are the only solar technology able to provide high-temperature heat without a combustion step or a mechanical or electrical-to-thermal conversion step. Third, solar thermal energy systems can be used to retrofit (supplant or supplement) the basic heat sources of existing industrial and utility plants, a feature that can smooth the transition from nonrenewable to renewable energy sources. Finally, solar thermal technology can be integrated with thermal energy storage systems, thus delivering heat well beyond the daylight hours. This results in considerable flexibility in the use of solar thermal systems and enhances their potential to deliver process heat and electricity at low cost even at night. Solar thermal energy systems can therefore be a very reliable source of process heat and electric power.

Total U.S. energy consumption in the form of process heat is estimated to be approximately 12 quads annually. Since solar thermal systems can deliver heat over a wide temperature range, they have the ultimate potential of annually displacing 1 - 2 quads of energy now produced from fossil fuels. In the utility sector, about 23.5 quads of energy were used in 1980 to produce electricity. The solar thermal potential in this area is estimated to be 2-4 quads. However, different penetration scenarios can be developed depending upon the assumed rate of technology development and future cost of solar-derived energy relative to conventional energy sources. Therefore, further R&D must stress innovation aimed at eventual system cost reduction to fully realize the potential of this resource.

Solar thermal energy systems consist of components that rely almost exclusively on traditional labor skills for their manufacture. These include the mass production capabilities of the metal, glass, and plastic industries. The relatively large-scale industrial capacity required to produce the requisite hardware economically may provide an added benefit for the nation in terms of industrial growth based on new, domestically developed technologies. For instance, displacement of 1 quad/yr will require the installation and use of about 330 million m^2 of collectors.

SERI's activities address two collection techniques: concentrating collectors and solar ponds. Concentrating collectors use reflective or refractive surfaces to focus or concentrate the sun's rays on a small area where the radiant energy is converted to either latent or sensible heat. Four concentrator concepts are under development: hemispherical bowls, parabolic troughs, heliostat fields with tower-mounted central receivers, and parabolic dishes. A solar pond is a shallow (several meters deep) body of salt water capable of converting solar energy to sensible heat at temperatures to 90°C (194°F), then storing it for extended periods (weeks to months). After the solar energy is converted to heat, either by a concentrating collector or a solar pond, the energy can be used directly or converted to mechanical or electrical power.

A cadre of scientists and engineers at SERI, other major national laboratories, and many private firms are working jointly to make solar thermal systems a competitive heat

source. Private industry is relied upon to complete the necessary technology development and provide the commercial products. Excellent progress has been made in refining the technology in the last few years.

Operational systems, such as parabolic trough systems for industrial process heat, and the nearly completed 10-MWe solar electric power plant near Barstow, Calif., provide data on both system and individual component performance. These data allow comparisons with technical predictions and form the basis for future improvements and innovations through carefully directed research.

The national program continues to emphasize long-term research as its first priority. Major research needs are derived from the necessity to substantially reduce the cost of concentrators, which account for about 50% of the system costs. The highest priority research focuses on developing new materials or combinations of low-cost materials for specific solar concentrators. New and innovative concepts and concentrator designs are needed so that industry can produce concentrators at lower cost even in small quantities. Further research is also needed to develop high-temperature receivers and reactors to integrate solar thermal systems into conventional electric, fuel, and chemical generating processes.

Objectives and Content of SERI's Research

Consistent with the major research needs of the national program, SERI's work emphasizes long-term research and development on materials, components, and research systems required to realize competitive solar thermal energy in the free marketplace.

SERI's programs are based on a comparison of solar thermal systems with conventional thermal systems to identify required areas of research and to achieve program objectives at minimum cost. Specific tasks are then defined that range from basic research on materials concentrated photon conversion and heat transfer mechanisms unique to solar thermal processes to proof-of-concept testing on advanced prototype concepts and systems. The major thrust is to solve broader-based problems in areas having wide potential. This allows for a handoff to the private sector in time for development of specific products and systems that can deliver solar thermal energy competitively with conventional fuel sources.

SERI has defined four major research and development objectives within the program. The first is to conduct necessary research to make available, in coordination with the industrial research sector, new and improved materials leading to enhanced system durability. The second is to investigate concepts for low-cost concentrators suitable for low- and intermediate-temperature thermal applications. The third is to conduct basic and applied research to understand the mechanisms of photon energy conversion and heat transfer. The fourth is to contribute substantially to the broad technology base necessary for the successful evaluation and application of new materials and concepts to meet the specific needs of solar thermal systems.

In the Materials Research area, procedures will be established to conduct accelerated testing of concentrators in controlled environments. Through these tests and through an understanding of the mechanisms of degradation, the service life of mirrors in the outdoor environment can be predicted. Characterization of glass and polymers will support suitable materials development. These efforts should provide tools for industry to evaluate their own products and guide their efforts to successfully use new materials in solar thermal systems.

SERI, through industry participation, will examine the potential of new and innovative concentrator designs so that even at low industrial production levels, desired lower costs can be achieved. This effort will include design, fabrication, and testing of prototypes at the SERI solar thermal test facilities to verify potential of these new concepts. Industrial participation ensures that new design features and new materials developed and evaluated within the SERI program will be used in future concentrators produced by industry.

Within the SERI program, high-temperature receivers and reactors for potential use in future thermal systems will be investigated and evaluated. Research will be focused on evaluating the compatibility of different containment materials (e.g., high-temperature, nickel-based alloys and ceramics) with gaseous or liquid heat transfer media.

Future Directions and Major Decisions

The program direction may shift from materials development and low-cost concentrators as the results of present research are obtained and as industry uses these results for their own designs. Future research will emphasize thermal processes, i.e., use of solar thermal systems in fuel and chemical production. This will include high-temperature receivers and reactors, wavelength/flux separators, and the durability of high-temperature metals and ceramics in the severe and unique concentrated solar environment. While data on these materials are available, they are generally under steady-state conditions instead of the cyclic ones induced by solar systems. The specific direction for research in the FY 1984 to FY 1987 time frame will depend on determining the potential of solar thermal energy in fuels and chemicals processes, the needs for high-temperature receiver and reactor improvements, and the technology readiness of materials and new component designs for low-cost concentrators.

Value of Accomplishments and SERI's Role

SERI's research and development will assist the Solar Thermal Program and the solar thermal industry in achieving technology cost and performance targets. SERI's unique materials assessment and testing capability will assist industrial producers in verifying their product potential and will guide their resources toward high-payoff technologies.

Examples of previous SERI contributions include stimulating thin glass development by the Corning Glass Company and polymer-based reflector research by the 3M Company. In the former, SERI and Corning Glass worked together to achieve an improved, low-cost product that could be manufactured and sold in the marketplace. This joint effort was successful in convincing major heliostat manufacturers such as Martin Marietta to use thin glass in their future designs. In the latter, 3M Company may improve their commercial aluminized acrylic reflector film so as to achieve longer life by using the SERI-developed Fourier Transform Infrared Spectrometer rapid degradation evaluation technique.

SERI's role can be divided into two specific areas: investigation of new ideas, materials, and advanced concepts for introduction into the industrial complex and eventual wide-scale use in solar thermal components; and evaluation of the performance and durability of materials, prototypes, and systems produced by industry to verify their potential and thus establish a technology base for future solar thermal systems. This evaluation, when conducted by SERI, makes available to industry the unique laboratory and outdoor test facilities difficult and expensive for industry to duplicate. Furthermore, the industry benefits from an unbiased evaluation of its concepts.

Resource Requirements

It is estimated that funding for this activity will vary between $3.99 million and $4.1 million annually for the duration of the planning period. The activity will employ approximately 43 people.

New Initiatives

Two new initiatives are proposed for this area of research: solar concentrators and wavelength/flux separation [see Section II-A (2a)].

Active

Resource Potential and Research Needs

The sales of active solar space heating, cooling, and domestic hot water heating systems using nonconcentrating collectors have shown a steady growth rate over the past five years. The latest information from EIA's collector manufacturers' survey indicates 5.76 million ft^2 of glazed flat-plate collectors were manufactured in the United States during the first six months of 1980. These sales are located primarily in the sun belt states and are realized primarily with the help of federal and state tax credits. Even with these incentives, effectiveness of active solar systems is highly dependent upon climate and the cost of displaced fuel. These regional factors limit the widespread growth of today's active solar system into other areas of the country. Also, with the federal tax credit due to expire in 1986, current system costs to the consumer will rise significantly and reduce solar use unless cost reductions can be achieved.

SERI's research is therefore focused on investigating innovative, next-generation concepts and systems. The resulting technology base can be passed off to the solar industry in time to develop marketable products in the 1985-1990 time frame. Emphasis is being placed on the use of new materials and system configurations applicable to active systems. This work will be conducted in close cooperation with the current solar industry and will support achieving cost goals of about $\$100/m^2$ of collector area for installed systems that will operate with efficiencies comparable to or better than present systems.

Objectives And Content of SERI's Research

SERI plans to address several critical research areas within the time frame of this planning period in order to assist industry in making active solar systems competitive in the latter half of the 1980s. Materials research on potential low-cost/long-life glazings, coatings, and polymers applicable to flat-plate collectors will be conducted. In addition, concept development and prototype testing activities for innovative collectors and other system components will be performed as well as concept studies of heating and cooling systems to reduce overall system cost by combining or eliminating components.

SERI's active solar research is conducted in concert with other research in solar thermal technology. While solar thermal research addresses concentrating higher temperature systems, there are many technology spinoffs, particularly in the materials area. For example, the photodegradation of transparent and reflective polymers has application within all temperature ranges.

FY 1982 is a transition year for the active program in which activities such as reliability and maintainability research on current systems and the facilitation of the codes and standards process will be brought to an orderly conclusion. Current activities are principally directed toward materials, innovative components, and cooling systems research. The materials and cooling systems research is directed toward the development of component concepts which could be the basis of significant cost reductions in future space-conditioning systems. Research priorities are identified through the analysis of performance and costs of contemporary systems. Areas for improvement are assessed by their risk/benefit and new research tasks appropriately identified. FY 1982 tasks identified by this process include testing and evaluation of high-performance drier wheels for desiccant systems and laboratory evaluations of the long-term stability of low-cost polymer component collector containers and glazings.

Another element of SERI's FY 1982 active solar program was initiated in FY 1981 and is directed at reducing solar heating systems costs through the development of innovative packaged space-conditioning systems. This effort is being carried out in close cooperation with the private sector and has a large subcontracting component. SERI will stimulate innovation in the private sector by funding the initial development of cost-effective, active solar, space-conditioning systems. The effort in FY 1982 and beyond is funded by carry-forward FY 1981 resources.

Future Directions and Major Decisions

SERI's active solar research for FY 1982 is focused upon the establishment of a technology baseline in terms of performance, cost, reliability, and standardization of systems using available components; and research into materials and concepts that can be used as the basis for advanced components and systems. SERI is currently integrating all solar radiation heat technologies (active, passive, and solar thermal) into a centrally coordinated R&D program within the Solar Thermal and Materials Research Division. These systems all work on the same principle—collection, transport, storage, and controlled release of thermal energy from solar radiation. By combining the research in materials, components and systems, SERI is in the unique position of covering all temperature ranges and thus fostering a creative environment for synergism across these applications.

Value of Accomplishments and SERI's Role

Current activity attempts to provide industry with options to achieve the free market breakthroughs needed for the long-term growth of the solar industry. Successful accomplishment will contribute to the technology base necessary for the solar industry to develop truly competitive ($5/MBtu) active solar systems. For example, SERI's materials research in long-life/high-performance polymers could result in improved collectors that industry could readily market.

SERI is in a strong position to perform active solar research because it has an interdisciplinary scientific staff and facilities, exercises independent judgment, and has valuable lines of communication to users and industry necessary for the broad use of research results. SERI's efforts will foster the development of improved systems by communicating relevant research results; coordinating the activities of involved federal laboratories, industry, and university participants; and providing an independent assessment capability to the solar community.

Resource Requirements

It is estimated that funding for this activity will be $1.2 million annually for the duration of the planning period. The activity will initially employ approximately 20 people and will stabilize at approximately 13 people.

New Initiatives

Two new initiatives are proposed for this area of research: Low-Cost Concentrating Collectors and Solar Ponds Research [see Sec. II-A (2a)].

Passive

Resource Potential and Research Needs

The existing building stock presently consumes a third of the total U.S. energy budget. The energy consumption of these buildings on a Btu/ft^2/yr basis is one of the highest in the world. Consequently, the potential for energy efficiency and renewable energy use in buildings is perhaps the greatest of all the energy end-use market sectors at this time. Passive, combined passive, and active solar systems (hybrid systems) can be integrated into new and existing buildings to provide a major portion of their heating, cooling, and daylighting needs. The proper design and application of passive technology in combination with active, photovoltaic, and energy conservation technologies could reduce U.S. building energy consumption by more than 50% or 17 quads* annually by the year 2000.

Although there is a growing theoretical and performance data base for these systems, little is known about their integrated performance within actual buildings. Additionally, current ASHRAE methods, the primary source of design information for architects and engineers, do not adequately address passive and hybrid systems.

The technology base necessary to develop more sophisticated analysis and design tools requires significant scientific improvements. First, the thermal interaction between various heating, cooling, and lighting components must be characterized through detailed, laboratory quality bench- and full-scale experiments. Second, accurate and reproducible analytical results must be achieved through detailed computer code development and validation against empirical test data. This will provide a basis for wide-ranging investigations of the interaction of a variety of passive heating, cooling, and lighting systems in combination with active and energy conservation systems. Additionally, new and improved materials and components are needed to reduce present system costs or improve thermal performance. These will support broader competitiveness with conventional energy alternatives.

Objectives and Content of SERI's Research

SERI's passive research activities for FY 1982 have four major objectives encompassing all tasks. The first objective concerns buildings science and materials research to characterize fundamental heat transfer in passive systems and the investigation and testing of advanced materials and components. Tasks within this area include developing new convective heat transfer coefficients for single zone surface-to-surface coupling, testing of innovative passive thermal control techniques, and investigating a high light-transmission and R-value window system.

The second objective relates to the collection and analysis of performance data from instrumented residential and commercial buildings for baseline evaluation of passive components, systems, and analysis tools. Research activities for FY 1982 include evaluating the performance of approximately 70 residential buildings with passive systems using a low-cost methodology developed by SERI and characterizing the performance of three passive retrofit systems through detailed testing at the SERI test site.

The third objective builds upon the first two by evaluating, validating, and developing

*1 quad = 10^{15} Btu.

advanced calculational procedures for predicting the thermal performance of passive building components and systems. Large building energy analysis simulations are used to understand the interdependence of passive materials, components, and systems within the context of the entire building and to generate new design methodologies. The output of this research is made available to professional societies such as AIA and ASHRAE for review and inclusion as standard practice.

The fourth and last objective involves the completion of systems development activities for passive manufactured buildings. Prototype systems designed during FY 1980 and FY 1981 will be constructed and tested during FY 1982. The results from this testing will define the cost/performance requirements of passive manufactured buildings and will identify materials, components, and systems level research needed to improve performance or reduce costs. Industry is 90% cost sharing in this task and will be in a position to further develop and commercialize the systems that are tested from this program.

Future Directions and Major Decisions

SERI's passive research over the past three years has established the foundation and definition of need for advanced research in thermal sciences, materials, components, and prototype systems development. Future research to be undertaken includes fundamental heat transfer research to understand and to control passive cooling processes; innovative materials research in glazings and phase change storage; advanced component and prototype systems research leading to high-performance integrated systems; and the creation of a technology base to support the integration of passive systems with active, photovoltaic, and energy conservation techniques. SERI's FY 1982 activities establish a basis for a balanced program of materials and heat transfer research, and component and prototype systems research and testing in FY 1983 and beyond.

This direction is facilitated by SERI's extensive capabilities in material and thermal sciences. These capabilities provide a scientific base for all the solar heat technologies and provide the opportunity for innovative spinoffs and cooperative research activities.

Value of Accomplishments and SERI's Role

The achievement of SERI's passive research objectives for FY 1982 and beyond will enable the building industry to make sound investment and design decisions on the application of passive and hybrid systems to new and existing buildings. This, in turn, will result in significant national energy savings. The research proposed represents areas where the building industry historically has not participated because of high risk, high cost, and specialized skill requirements, and where SERI has established a national and international reputation of excellence.

A case in point is SERI's outdoor laboratory for daylight research, one of the finest such facilities in the world. Industry requires the information from this facility to better design integrated daylighting systems in buildings and to develop better glazings, controllers, and artificial lighting systems. SERI has developed a unique measurement and analysis capability to provide the industry with this information. The building industry in general cannot afford the cost of the apparatus and the specialized talent to acquire and to analyze the data.

SERI's role is one of complementing and supplementing the space conditioning and lighting research activities of the building industry and the national laboratories in areas of

advanced research and development in materials, heat transfer, components, and systems. SERI has the appropriate staff capabilities and facilities to investigate the integration and interaction of passive systems and components in energy-efficiency buildings.

Every task proposed has been coordinated with industry and complements their own privately funded research activities. The transfer of SERI's research results to industry has been clearly established so that industry easily and naturally continues the development and commercialization of work transferred by SERI.

Resource Requirements

It is estimated that funding for this activity will be $1.35 million annually for the duration of the planning period. The activity will initially employ approximately 30 people and will stabilize at approximately 20 people.

New Initiatives

Two new initiatives are proposed for this area of research: solid-to-solid phase change storage and innovative window technology [see Sec. II-A (2a)].

Information

Resource Potential and Research Needs

The success of SERI research programs, or of any other nationally sponsored research, depends heavily on a coordinated effort to gather resulting data and interpretations and, in turn, to transmit these to the most appropriate sectors for industrial use and practical application. This information transfer process has received continuing attention at SERI and a concise program has been developed.

This program is staffed to address the information component of each technology under SERI research, and to package and deliver resulting information to appropriate audiences of scientists and engineers in the industrial and commercial sectors. The SERI staff involved in the Solar Information Systems Program includes professionals in technical writing and editing, data compilation, computer-generated publishing, and targeted information transfer. With SERI's restructured focus on long-term, high-risk research, this program has been oriented to provide a direct interface with researchers in all technologies, allowing the entire range of SERI technical information output to be processed for specific dissemination.

Successful accomplishment of the program requires the use of publishing and transfer mechanisms specifically suited for SERI's priority information audiences. Although the program has previously been successful in identifying and prioritizing the needs of technical users of specific information, information-needs research will be a continuing requirement for accomplishment of goals in all technologies.

Objectives and Content of SERI's Activity

The objective of this program is to effectively transfer important research-derived information to the technical audiences which can most profitably apply it, in formats suited to their use. This transfer process is accomplished through the following activities:

Needs Research and Product Planning. SERI's solar information program recently produced a comprehensive study on information needs of users for research and development in each solar-related technology. Results from this research are now guiding the information product planning process which sets an agenda for production of reference guides, manuals, and compendia in specific research areas. This agenda has been set forth for concurrence by SERI and DOE program management in the FY 1982 Information Product Development Plan. Because information for any technical audience changes rapidly, needs research and product evaluation are continuing activities to assure responsiveness of the entire information program.

Data Compilation. SERI has refined a substantive capability to collect and format data important to scientific research and the development of solar technologies. These data serve as a principal information source for compilation of information products.

Research Interface and Quality Assurance. Providing the interface between R&D program management and publication specialists is the most important new component of this program. The technical staff that works directly with SERI program

managers also reviews products to assure that they are acceptable for outside distribution and have received adequate peer review from both inside and outside DOE and SERI.

Information Product Development. From research data and assessments gathered from SERI and elsewhere, finished information products such as published data compilations, manuals, and special research compendia are packaged for specific audiences, and visual materials, as appropriate, are designed and produced. All are technical in orientation and are prepared to fulfill specifically identified audience needs. SERI produces a comprehensively indexed Desktop Library of summary information from each SERI technical report, updated semiannually. Information products are also prepared to serve the identified needs of participant organizations in the Solar Energy Information Data Bank.

Information Transfer. SERI uses the most effective means available to transfer information to assigned audiences. These means include publication by technical publishers in the open market and government publications outlets (Superintendent of Documents, National Technical Information Service, National Audiovisual Center, DOE Technical Information Center), limited data base access, and, as appropriate, seminars and technical exhibits. To assure effective dissemination, SERI prepares announcements to inform targeted audiences of the availability of information through a designated publisher or service. A small technical inquiry staff provides outside requestors from the research and industrial communities with technical information, conveyed directly or indirectly by referral to appropriate SERI scientists.

Information Program Coordination. SERI is responsible for coordination of the Solar Energy Information Data Bank (SEIDB), a national network of solar technical information service organizations, and for direction of a solar information exchange program between SERI and various foreign countries.

Future Direction and Major Decisions

SERI collects and develops information from R&D sources often unknown or inaccessible to private publishers. SERI's interest in effective information transfer is well served by providing interested publishers with packaged information in fully substantiated and finished form, for appropriate distribution through the commercial market. Arrangements of this sort have been made on a trial basis and pursuit of similar agreements for cooperative publishing will be a major thrust of this program in the future.

During FY 1982, if approved by OMB, SERI will undertake publication of a quarterly scientific journal, the SERI Solar Research Journal. This publication will summarize important information emerging from SERI R&D and will include technical articles contributed from both inside and outside the Institute. Key emphasis will be placed on publication of research findings as quickly as they are substantiated and developing an appropriate distribution plan, guaranteeing receipt by a priority audience.

A major decision that must be addressed in FY 1982 is where to curtail programs during FY 1983 to meet the reduced budget projected for that year. Subject to more specific guidance from DOE Program Management, reductions can be expected in the number of information products currently planned, the amount of data compiled, the amount of support provided to network participants in the SEIDB, and the services provided to selected

audiences of information seekers. In any case, the program will be structured in close coordination with DOE to meet the most important information needs of the solar energy technical community.

Value of Accomplishments and SERI's Role

This program assures that the maximum benefit is derived from the federal investment in solar research and development. It serves to accelerate the pace at which research accomplishments spawn new technical developments and commercial applications. The success of the Solar Information Systems Program is highly dependent on continued input from DOE Program Management; future developments will be influenced by program review and an open exchange of comments and ideas.

Resource Requirements

Funding for this activity will approximate $3.2 million initially and $2.0 million annually for the duration of the planning period. The activity will initially employ approximately 40 people and will stabilize at approximately 28 people.

New Initiatives

No new initiatives are presently being proposed for this program.

b. Director of Office of Energy Research

The research programs at SERI that are supported by the Office of Energy Research (OER) Basic Energy Sciences (BES) Programs are exploratory, basic investigations which provide a fundamental crosscutting base for applied research directed at specific program areas. This research has long-term relevance to the various energy technologies described in the AS/CE section and is an important part of the SERI research effort which should be strengthened in the future. The research is concentrated primarily in the materials and photoconversion areas and is supported by the following BES programs: Materials Sciences, Biological Energy Sciences, Chemical Sciences, and Advanced Energy Projects.

Materials Sciences

Resource Potential and Research Needs

Basic and applied research is performed with the long-range goal of improving the collection of incident solar radiation. Materials and configurations are sought to improve heliostat, trough, and dish-reflecting surfaces; concentrating optics; and structures with potential for application in many of the technologies. The potential impact from improvements in reflecting surfaces, concentrating optical materials, and lightweight advanced structures has been addressed in the specific technology program description earlier.

A major R&D requirement is to identify and eliminate causes of degradation of the optical performance of surfaces used in solar applications, e.g., mirrors, polymers, and glasses, all of which require long-term durability for applications. Long-life materials can best be obtained by isolating causes of the performance degradation and using these as a basis to modify existing materials or processes or to conceive new materials or processes that will eliminate or minimize degradation. In the broadest sense, durable materials with high performance for collectors, membranes, and thermoelectric devices are necessary to capture solar potential on a large scale.

Objectives and Content of SERI's Research

The objectives of the SERI materials research efforts are to identify the degradation mechanisms affecting the performance in solar energy conversion systems and to develop new materials options. Basic research will be undertaken to lay the foundation for developing stable silver/glass or silver/acrylic mirrors, durable acrylic or polycarbonate polymers, and glasses not subject to solarization.

The emphasis of the work in FY 1982 will be on the stability of glass/silver and silver/polymer interfaces and photodegradation of polymers such as polymethylmethacrylate, polycarbonate and other acrylics. Experimental methods will include real time and accelerated testing of materials exposed to real and simulated solar terrestrial environments and the analysis of compositional changes with materials and surface analysis instruments.

Future Directions and Major Decisions

The objectives of the present research on mirrors and polymers could shift to different but more promising materials as results are obtained. Major decision points on the magnitude of effort to be applied to the specific objectives will be required as additional research information is obtained.

It is anticipated that the effort in polymer photodegradation would move into additional polymer/metal (oxide) systems, permeation of polymers, and nonlinear effects. The effort to understand the causes of mirror degradation, to conceive and to provide new reflective materials, and to understand and to reduce the solarization of glasses is expected to receive additional emphasis.

Value of Accomplishments and SERI's Role

The potential payoff of this effort is making durable materials for solar thermal concentrators available for use in active heating, photovoltaic, passive, and solar thermal technologies. In addition, the long-range applied research will increase our basic understanding of solar radiation effects on candidate materials for solar applications. Major components of this work will increase our knowledge in materials science, polymer science, analytical chemistry, solid-state physics, physical chemistry, and interface science, providing a technology base for a very wide range of applications by industry.

SERI has unique capabilities for carrying out the various components of the materials research. These include operating laboratories, multidisciplinary expertise in the appropriate areas of materials science, and a synergism between the scientists engaged in the basic work and the program researchers and managers who represent the technologies that would ultimately benefit from the work.

Resource Requirements

It is estimated that funding for this activity will vary between $225 thousand and $355 thousand annually for the duration of the planning period. The activity will employ approximately 3 people.

New Initiatives

A number of new initiatives are currently planned for Materials Science [see Sec. II-A (2b)].

Biological Energy Sciences and Chemical Sciences

Resource Potential and Research Needs

Photoconversion research attempts to develop solar energy conversion systems that use sunlight to produce fuels and chemicals in a single step with high conversion efficiencies. Examples of important chemical reactions that may make use of sunlight are water splitting to produce hydrogen; photoreduction of carbon dioxide and water to hydrocarbons, alcohols, and other useful organic compounds; photofixation of molecular nitrogen; and decomposition of organic compounds and waste materials into hydrogen and carbon dioxide. Photoconversion differs from biomass conversion in that it is a single-step, solar radiation-driven process that generally uses simple starting materials and can involve a variety of artificial or man-manipulated systems or organisms (such as inorganic semiconductors, organometallic compounds, organic sensitizers, photosynthetic bacteria, or green algae).

Four areas of research need to be pursued to realize the potential of photoconversion: photobiology, photochemistry, photoelectrochemistry, and synthesis/catalysis. In photobiology, photosynthetic microorganisms are studied as converters of radiant energy into chemical energy. In photochemistry, new molecular compounds are studied as solar sensitizers and photocatalysts. In photoelectrochemistry, semiconductors are investigated as the photoactive element in concert with a suitable electrolyte that produces fuels and chemicals from sunlight. Synthesis and catalysis activities involve the study and creation of new molecular species for use in all of the photoconversion approaches.

Objectives and Content of SERI's Research

Photobiology. Research is being conducted to determine the feasibility of obtaining organisms that produce hydrogen through a less energy-intensive pathway; utilize fundamental information about the algal enzyme hydrogenase and its physiological role to devise biochemical and/or genetic techniques for algal hydrogen-producing systems; determine the mechanism of hydrogenase activation during anaerobic incubation of algal cells; isolate and purify algal hydrogenase suitable for detailed biochemical and physical characterization; and investigate the properties of bacterial photosynthetic structures (chromatophores) and reaction center complexes in monolayer and multilayer areas.

Microbiological, biochemical, and genetic techniques will be used to identify the electron transport components and pathways associated with hydrogenase activity in photosynthetic bacteria. The mechanism of hydrogenase activation in vivo will be studied by defining the energy requiring aspects of the activation process and establishing the degree of involvement of new protein synthesis. The electron transport mechanism between semiconductor electrodes and oriented reaction centers and chromatophores will be established.

Photochemistry. The objective of research in this area is to understand the fundamental molecular properties needed to assemble synthetic photoreaction centers for artificial photosynthesis. Laser flash photolysis, low-temperature continuous wave spectroscopy and fluorescence measurements will be performed on a variety of molecular complexes. The kinetics and spectra of light-induced changes in these systems will be used to determine the nature of the transient charge-separated

state(s) and the electronic state of the donor species from which the transferred electron emanates.

Photoelectrochemistry. The objective of research in this area is to study and understand the basic nature of the charge separation across semiconductor-electrolyte interfaces, including the injection of nonthermalized electrons or positive holes from illuminated semiconductors (hot carrier effects) and band-edge movement (unpinning phenomena) and its consequences; understand the detailed energetics of p/n photoelectrolysis cells utilizing simultaneously illuminated n- and p-type photoanodes and photocathodes; and understand the nature and mechanisms of electrode stabilization by organic-conducting polymer films.

Hot carrier effects will be studied both from theoretical and experimental viewpoints. Theoretical work on the kinetics of hot carrier charge transfer across semiconductor-liquid interfaces will be done to detect hot carrier injection by monitoring chemical reactions outside the semiconductor band gap and by collision excitation of luminescent molecules. The effects of band-edge movement under illumination will be studied by photocapacitance experiments. The p/n photoelectrolysis cells will be studied using n-type layered chalcogenide compounds to photoelectrolyze hydrogen iodide, hydrogen bromide, and water. The possibility of stabilizing small band gap semiconductors against photooxidation in the presence of oxygen evolution by using conducting organic polymer films will be investigated.

Synthesis/Catalysis. The objective of research in this area is to synthesize, characterize, and evaluate potential molecular catalysts for the photoconversion of various substrates into fuels and chemicals.

The research effort will involve the synthesis of new inorganic, organometallic, and metal cluster compounds for the coordination and activation of water, carbon dioxide, carbon monoxide, and hydrogen. These transition metal complexes will be used in stoichiometric and catalytic light-induced redox reactions to yield hydrogen, ammonia, methanol, organic acids, esters, and other carbohydrates. The development of these catalysts will involve the synthesis of new bridging ligands and dinuclear organometallic complexes for homogeneous photosensitization and redox reactions, as well as new ligands for the preparation of surface-bound and polymer-attached complexes for photoelectrochemical studies. Various organometallic complexes will be synthesized and characterized for similar studies. The characterization and evaluation of these photoconversion catalysts will involve electrochemical, structural, spectroscopic, and mechanistic studies.

Future Directions and Major Decisions

All of the photoconversion research activities involve long-range basic research. New and unexpected discoveries frequently occur and these may result in redirection of the research program. Such changes are not generally predictable.

Value of Accomplishments and SERI's Role

The basic knowledge obtained will provide a technology base for applied research on photoconversion concepts. The successful development of photoconversion systems would be a major breakthrough for meeting the energy requirements of the United

States. Such systems could provide abundant and affordable liquid and gaseous fuels from renewable resources; some fuels (e.g., hydrogen) will also be nonpolluting. Valuable chemical feedstocks may also be produced at competitive costs starting from raw materials other than fossil supplies.

SERI's photoconversion research staff is a unique collection of scientists from a wide spectrum of disciplines that are required for photoconversion research; these disciplines include microbiology, biophysics, biochemistry, plant physiology, photochemistry, electrochemistry, physical chemistry, inorganic and organometallic chemistry, and solid-state physics. No other group in the United States has such a range and scope of scientific backgrounds devoted to the overall goal of producing fuels and chemicals from sunlight. The group has excellent interactions and synergisms that stimulate progress and cross-fertilization of new ideas. In addition to the strong scientific interactions within the photoconversion group, excellent interactions occur with other SERI research staff in biotechnology, thermochemical, electrochemical, materials, and photovoltaics groups. This further enhances the uniqueness of the photoconversion staff to conduct research in the production of fuels and chemicals from sunlight in a single step.

Resource Requirements

It is estimated that Funding for Biological Energy Sciences will vary between $85 thousand and $135 thousand annually for the duration of the planning period and will employ 1 person. Funding for Chemical Sciences is estimated to vary between $440 thousand and $710 thousand annually for the duration of the planning period and will employ 4 to 5 people.

New Initiatives

A number of new initiatives are currently planned for this area described in Sec. II-A (2b).

Advanced Energy Projects

Resource Potential and Research Needs

Very large resources of low-grade thermal energy remain unused because of the difficulty of using them directly or upgrading them to a more valuable and transportable form. Solar thermal energy in the thermoclines of the oceans and in solar ponds is in this category as is geothermal brine and many sources of industrial waste heat. A conversion system is needed to make better use of these resources. Such a system should require little maintenance, have an inherently long life, and be modular. Modularity is important because low-grade thermal energy resources are usually disperse. While organic rankine cycles may in principle be suitable, maintenance and lack of modularity may be prohibitive factors. Thermoelectric systems have the potential for meeting these needs.

Objectives and Content of SERI's Research

The objective of this SERI task is to test thermoelectric concepts for effective conversion of low-grade thermal energy. The thrust of the SERI research has been to develop new generator designs using thin films that are optimized for low-grade thermal energy conversion, and to investigate fabrication techniques that can lead to reproducible material over a large area.

The FY 1982 effort is devoted to the fabrication of prototype devices based on our novel designs (patent applied for); thin film thermoelectric devices using sputter-deposited bismuth-antimony-selenide-telluride semiconductor alloys. Energy conversion efficiency will be evaluated in the laboratory, and if promising, prototype devices will be assembled into a small generator system to test technical feasibility.

Future Directions and Major Decisions

If research is successful in meeting performance goals for the prototype thermoelectric generators, an engineering subsystem development effort may be warranted. Industry has expressed interest in the research and may pursue engineering development once laboratory proof-of-concept has been demonstrated. However, it anticipated that basic materials work is required to provide thermoelectric materials with optimum performance and durability.

Value of Accomplishments and SERI's Role

Successful development of an effective thermoelectric converter for low-temperature thermal resources would have several benefits. The potential for more dispersed, base-load electric power generation capacity would be enhanced with consequent increase in power system reliability and security. Many energy-intensive industrial activities, such as oil refining, glass production, metal working, ceramics manufacture, etc., could produce part of their own electric power.

At present, the concept of thermoelectric conversion of low-temperature thermal energy to electricity is an unproven, high-risk area of exploratory research. As such it is an appropriate activity for SERI and is not likely to be undertaken by the private sector.

Resource Requirements

Funding for this activity for FY 1982 is $100 thousand. One person will be employed by this activity for this year only.

The funding is based on the interim AS/CE guidance of August 5, 1981. FY 1982 is the final year of funding of a three-year program with the Advanced Energy Projects Program. Funds are requested for related basic materials research in this area in Section II-A (2b).

2. NEW INITIATIVES

The new initiatives discussed in this section are the result of targets of opportunity identified as a result of current programs. Occasionally they are the natural extension or expansion of current programs in areas requiring further research or development.

Dollar amounts for all new initiatives are included in the appropriate Resource Summary Tables in Sec. V.

a. Assistant Secretary for Conservation and Renewable Energy (AS/CE)

Photovoltaics

Need for Initiatives

In the Photovoltaics program, new initiatives are being prepared for solid-state research on self-supported thin semiconductor films; innovative research of hitherto unexplored photovoltaic material, amorphous materials other than silicon, electrochemical cells, organic semiconductors, high efficiency (greater than 30%) concentrator solar cells, stable organic dyes for luminescent solar collectors and thin-film gallium arsenide; research to study the physics associated with cell and module degradation; and additional assessment of solar radiation resources in areas not covered by the current data base.

These activities are needed to provide a research base from which additional and better techniques can be identified and developed by private industry for supplying renewable energy. In particular the research into the basic physical processes of photovoltaics will help eliminate the high risks which make it difficult for businesses to evaluate investments in the development of PV systems.

Objectives and Approach

The solid-state research on self-supported films and basic research on material/chemical processes will be primarily in-house activities which would lead to new innovative research on particular material systems. This research will then be continued to expand the basic knowledge and scientific understanding of these individual materials. A different area in which basic understanding is very important is the study and identification of physical phenomena that cause solar cell and module degradation. The objective of the degradation studies would be to determine the underlying causes so that appropriate amelioration activities could be undertaken in concert with further cell research. In the insolation resource assessment area, satellite mapping of solar radiation resources on a spatial scale of 1 to 50 km is critically needed to determine solar radiation resources in areas not covered by the current data base. Also the development of a time interpreting (day, month, year) spectroradiometer is needed to establish the effective terrestrial solar spectral distribution. All of these activities will be coordinated with the SERI PV AR&D Lead Center.

Value of Accomplishments and SERI's Role

On the whole, these new initiatives would result in a much stronger PV AR&D Program for identifying new and innovative concepts from which private enterprise can choose options for development and introduction into their own set of desired products and services. They would address critical research areas related to device stability and would allow for the exploration of innovative ideas.

Resource Requirements

Funding for this initiative will vary between an estimated $4.2 million and $7.3 million annually for the duration of the planning period. The initiative will employ between approximately 17 and 24 people.

Energy Storage

Thermally Regenerative Electrochemical Systems Initiative

One important SERI mission is the investigation of solar technologies that produce low- and medium-grade thermal energy. This initiative would investigate the conversion of this energy directly into electricity in closed cycle electrochemical heat engines. This concept is called Thermally Regenerative Electrochemical Systems (TRES) and holds significant promise for the efficient utilization of low-quality thermal energy.

Objectives and Approach

The objective of this initiative is to research new TRES concepts which have the potential to produce electricity using low- and medium-grade heat sources, and to produce fuels and chemicals and the storage of energy in the chemicals.

The TRES research will address the performance of the electrochemical cell, the feasibility of the regeneration, and an analysis of this type of system relative to the practical efficiency, required ancillary power, and potential applications.

Expected Value of Accomplishments and SERI's Role

The advantages of such systems are that electrochemical reactions at higher temperatures are more likely not to present kinetic problems; regenerations performed at lower temperatures are more likely to have less materials problems; they increase the possiblity of finding suitable ion-conducting solid electrolytes operative in the range of temperatures under consideration; and they are amenable to automatic operation.

The results will be beneficial to electric power companies that have low- and medium-grade heat sources available. These systems could be useful in cogeneration systems that can utilize any source of waste heat and could improve the overall efficiency of the power generating system.

The SERI staff has special expertise with electrochemical systems and has the necessary equipment and facilities available for conducting such research. The research will be conducted by the staff of the Thermochemical and Electrochemical Research Branch and the Energy Storage and Fuels Utilization Branch in the Solar Fuels and Chemicals Research Division. This research is sufficiently long range and high risk so that the private sector would probably not undertake such an endeavor.

Resource Requirements

It is estimated that funding for this initiative will vary between $449 thousand and $600 thousand annually for the duration of the planning period. The initiative will employ between 3 and 5 people.

Ocean Energy Research

Note: Ocean energy research is presently an ongoing activity at SERI. This research appears as a new initiative because it is not funded in the Administration's proposed FY 1982 Program. It does appear however that Congress will provide continuing funding for this program.

Resource Potential and Research Needs

The ocean environment offers unique sources of energy that show promise for augmenting conventional energy sources and for reducing dependence on imported fuels. In this regard, interest has turned to an investigation of the renewable energy resource potential of the oceans and the significance of the role they could play in adding a useful increment to U.S. energy requirements. Among the sources of renewable energy from the ocean are the temperature differences that exist between warm surface water and cold deep ocean water, wave action, tides, and current and salinity gradients.

Ocean Thermal Energy Conversion (OTEC)

The ocean thermal energy resource is estimated at 100 million to 10 billion MW. This represents an upper limit on the potential power capacity of this resource, and certainly only a small percentage of this calculated potential would ever actually be used.

Both coasts of Africa, the tropical west and southeastern coasts of the Americas, and many Caribbean and Pacific islands are situated where adjacent water possesses the year-round thermal characteristics required for operation of an OTEC power cycle. Potential areas of deployment in the United States include Gulf Stream waters off the U.S. southeast coast, the Gulf of Mexico, Puerto Rico, the Virgin Islands, Hawaii, Guam, Micronesia, and American Samoa.

According to a recent assessment of OTEC market potential, DOE has observed that entry of OTEC into a U.S. mainland market is unlikely unless or until modular plant concepts and alternate platform designs have been successfully operated in proof of concept experiments. It seems likely, however, that initial commercial implementation for OTEC technology will be in tropical island electric applications of 10- to 100-MWe replacement capacity. Puerto Rico, U.S. Virgin Islands, Hawaii, and Guam have expressed strong interest in OTEC, and economic, social, and political factors appear favorable for the development of island markets at these locations. They have favorable ocean thermal resources, and the oil-dependent island utilities located there would be competitive markets for early OTEC plants. Conceivably OTEC could deliver power to U.S. islands in the 1990s, if technical and economic feasibility were proven by the mid-1980s.

Although the electricity-to-shore-via-cable option appears to be the OTEC application nearest to being commercially competitive, it has been proposed for plants a long distance from shore that the power generated be used on-site for energy intensive refining and manufacturing processes on OTEC plant ships or at ocean energy industrial complexes. Provided the electricity is cheap enough to make a process economically feasible, the onsite production of chemicals, the synthesis of methanol, and the generation of hydrogen may have promising market potential. Also associated with ocean thermal systems are the possible options of producing food through mariculture, providing fresh water and extracting ocean minerals.

Both closed- and open-cycle OTEC systems hold promise for commercial applications. However, researchers in the United States regard the state of development of open-cycle technology as being less advanced (by several years) than closed-cycle technology. Because of the need in the open cycle to harness energy in low-pressure steam, large turbines must be used, degasifiers may be required to remove dissolved gases from the seawater, and large-scale direct contact heat exchangers must be developed before commercialization is feasible. Recent open-cycle studies are encouraging, however, and point to cost-effective solutions in all of the technical areas.

Other OTEC subsystems present technical problems that must be solved at reasonable cost. In particular, in the closed-cycle engineering program, viable solutions are being sought for the design and deployment of OTEC cold water pipes and submarine electrical cables.

Alternative Ocean Energy Concepts

Recent interest in other ocean energy devices is prompted, in part, by the fact that wave energy represents an alternative for geographic locations that derive a lesser benefit from use of direct solar. The Pacific Northwest and, to a lesser extent, the U.S. Atlantic coast are good potential wave energy sites. The promise of wave energy is that it is a more concentrated and persistant energy source than other solar alternatives (at 50 kW/m of wavefront). This arises out of the fact that waves are generated by wind over many square miles of sea-air interface. The historic perspective of past development activity is that extraction/conversion efficiencies of over 80% have been achieved. It is possible that wave focusing might further improve these efficiencies. This possibility improves the potential for wave energy to be a cost-effective source of energy.

The challenge of the wave program is to develop the concepts which make this potential a reality. Ocean engineering problems, particularly in the areas of mooring, storm survival, and power transmission have not been effectively addressed to date. The U.S. program is presently structured to develop wave-focusing techniques, define concepts within a power delivery system context, and identify the most promising wave energy extraction concepts. This process will establish the economic feasibility in wave energy and define appropriate proof-of-concept experiments.

Only one wave energy concept is currently under serious consideration and that involves the submergence of a ducted axial flow turbine in areas of significant natural water flow such as exists at the Miami-Bimini transect of the Gulf Stream. A 60-m-diameter turbine in this location could deliver over 5 MW of electrical power into the utility grid. Designs exist with potential to offer costs at about $\$1275/kW_p$. This low cost plus the opportunity to do significant at-sea experiments at small scale make this technique a prime candidate for successful development. The key issues being addressed are an evaluation of the amount of the resource and the amount that can be successfully extracted; the actual cost of the system; and equipment survival, maintenance, and other operational characteristics.

Objectives and Content of SERI's Program

SERI's research role in ocean energy is structured around the higher risk, second-generation, open-cycle OTEC systems and advanced wave and current energy extraction concepts. SERI is also working to develop a role in wood and other low-cost options for

the cold water pipe. The open-cycle OTEC research program has matured into serious experimental programs aimed at reducing the technical risks and uncertainties in three major areas: technical assessment of a large (100 MWe) low-pressure steam turbine concept; performance definitions of cost-effective, direct-contact heat exchangers; and fundamental knowledge of deaeration of seawater and relative effect of gas evolution on heat exchanger performance.

Specifically, direct contact heat exchanger module testing being conducted at our experimental facility is providing the necessary prototype data on evaporation and condensation processes unique in an open-cycle OTEC power system. The heat exchanger performance data will be used to arrive at a required baseline power module size from which reliable cost projections can be made.

A Prototype Wave Energy Converter (PWEC) has been fabricated and is ready for experimental testing during FY 1982. This device culminated from the efforts of DOE in cooperation with the International Energy Agency (IEA) in an effort to study the pneumatic type of wave energy conversion systems with several participating countries. Parallel with the testing program are continued fundamental thermodynamic and hydrodynamic modeling studies intended to achieve optimization of system power through sensitivity analysis. The comparison of theoretical predictions with experimental testing is intended to advance fundamental understanding of wave energy conversion.

As part of SERI low-cost collector composite research, advanced laminated wood, fiberglass, plastic films, and composites of these have been the focus of research to support advanced cold water pipes. This type of research draws on SERI's composites and structures expertise.

Future Directions and Major Decisions

OTEC research at SERI will allow the trade-off between contending conceptual open-cycle designs on a consistent and rational basis with experimental data and design methods that are reliable for extrapolation to a prototype-scale OTEC plant. On the basis of this activity, the potential for open-cycle OTEC in relation to other available renewable energy options can be made with high confidence.

A major decision will be made during FY 1983 after completion of trade-off studies on the options for a new baseline Claude Cycle (uses sea water as the working fluid) power system design. The decision will be made as to what subsystem scale is appropriate for proof of concept experiments. Facilities, test options, and cost will be major considerations. An advanced cold water pipe could also be tested.

Several steps remain before achieving an economically optimized pneumatic wave energy converter (PWEC). Following completion of the pending steady-state aerodynamic test of the bi-directional turbine, the information from this test will be incorporated into a refined and composite model of the oscillating water column (OWC) system. Use of this model should arrive at an optimized configuration for the water column and air chamber.

The next step will be an at-sea experiment (FY 1983) of the PWEC system, employing an improved air turbine and an optimized water column/air chamber configuration. Following a successful at-sea demonstration, the system will be subjected to further refinements with emphasis on structural considerations attendant to deploying the system in an

ocean environment. At this point, the final evaluation criteria will be one of economics, namely, cost per kilowatt-hour of electricity produced over the expected lifetime of the system.

Value of Accomplishments and SERI's Role

OTEC will not be fully credible to those responsible for purchasing and financing energy resources until its reliability has been demonstrated at a scale that can be confidently extrapolated to commercial-sited applications.

The potential advantages of OTEC have been shown through experimental trials on a small scale and conceptual design studies at a much larger scale. Detailed cost estimates show OTEC has promise for economically replacing oil for electricity generation in some regions of the United States and the world.

More fundamental engineering design and performance issues in open-cycle heat exchanger concepts will be assessed by SERI. The modular tests at SERI's existing low pressure and temperature heat exchanger test cell are a unique and valuable end product in understanding the fundamentals of direct contact heat exchange. SERI composite development analysis and mechanical testing capabilities can be used to support cold water pipe research.

SERI accomplishments in experimental testing are not limited to OTEC, but rather are employed to explore the fundamentals of low-temperature heat and mass transfer, common to many solar thermal energy research options. The power cycle of OTEC and its given thermodynamic boundary state is typical to many other solar thermal low-to-intermediate temperature options. Spin-off technology developments may result in the utilization of other forms of low-temperature energy (i.e., waste heat recovery, solar desalination, IPH, etc.).

Large open-cycle OTEC turbine development using 150-ft-diameter composite blades is compatible with the wind energy conversion program. The bi-directional turbine used in pneumatic wave energy conversion devices benefits from linking SERI expertise in aerodynamics and hydrodynamics. Unique analytical models developed at SERI and specific to OTEC and wave energy extraction are being used to assess system configurations in terms of overall performance with respect to the fluctuating ocean resource.

Resource Requirements

It is estimated that funding for this initiative will vary between approximately $2.1 million and $2.8 million annually for the duration of the planning period. The initiative will employ between approximately 8 and 12 people.

Thermal

Solar Concentrator Initiative

The development of an innovative solar concentrator subsystem exhibiting the potential for \$40-\$60/m^2 installed costs (in constant dollars) will significantly increase the value of medium- and high-temperature solar thermal energy for all potential end-use sectors. An accelerated effort could provide the technology base for individual achievement of such a goal by 1986.

Objectives and Approach

A program of materials research, subsystem concepts, and manufacturing process studies is required to meet the goal. Each one of these areas contains identifiable high risk/high payoff activities that can be arranged within an integrated schedule to minimize financial risks by sequencing technical risks. The majority of SERI's effort would be within the enhanced materials research and innovative subsystem areas with the private sector performing the manufacturing technology engineering during the latter stages of development. SERI's approach would follow these three stages: polymer research, thin glass reflector encapsulation, reflector concept development and supporting systems analysis; innovative concentrator prototype development and industrial engineering productivity studies; and testing and validation of concentrators, development of innovative collector focusing drives, controls, and support structures.

Value of Accomplishment and SERI's Role

Existing solar thermal technology, with substantial financial incentives and the application of mass production techniques, will be competitive for utility applications in the Southwest and selected industrial applications across the country within the decade. SERI is proposing that DOE embark on the long lead, relative low-cost research needed to introduce the next generation of solar thermal technologies into the economy. This next generation would greatly increase the value of solar thermal heat resources and make them competitive with several alternative fuel sources over much wider geographical areas. SERI has the facilities and scientific executive to perform this research in a timely and cost-effective manner.

Resource Requirements

It is estimated that funding for this initiative will vary between approximately \$4.0 million and \$6.0 million annually from FY 1983 through the duration of the planning period. Solar Thermal initiatives will employ a combined total of between 22 and 42 people.

Thermal

Wavelength and Flux Separation for Concentrators

Photons at certain distinct wavelengths and flux densities have the ability to excite chemical, electrical, and thermal processes. Hence, if photons from concentrated sunlight could be divided into beams with specific intensities and wavelengths that match specific photoactive processes, the value of the chemical reactions, electrical reactions and thermal reactions could be much greater than the value of converting all of those photons to heat and driving only a thermochemical process. Thus, concentrated sunlight could be partitioned and used to generate hydrogen, hydrocarbons, electricity, and thermal energy. Preliminary calculations show that if the heat value of an amount of concentrated sunlight is equivalent to fossil fuel at $5 per million Btu, the partitioning approach to yield fuels, electricity and heat may place the value of the same amount of sunlight at more than $10 per million Btu. It is this difference in the value of utilizing concentrated sunlight that this initiative seeks to quantify via research on a wavelength flux separator and preliminary exploratory research in matching photon processes to partitioned sunlight.

Objectives and Approach

SERI proposes to perform analytical and experimental research studies aimed at quantifying sunlight separation into distinct wavelengths and frequencies and coupling these light streams with photon processes. This activity would extend the scope of previous solar thermal fuels and chemicals research to include photon as well as thermal processes while introducing a new component, the wavelength flux separator. A number of concepts will be investigated to perform the wavelength and flux separation. These concepts will include prism engravings which use refractive index changes with wavelength to separate light as it is transmitted through a medium, dichroic mirrors which also use refractive index; and interference processes to effect separation, sequential fluorescent processes, and in-line cascaded selected absorption filters. The separation of concentrated sunlight into photon streams of known intensity and wavelength enables the development of photochemical, photovoltaic, and thermochemical conversion processes that can directly generate electricity, fuels and chemicals, and heat. The approach will be to study the separation processes and applicable photoconversion processes for concentrated sunlight applications that are not being developed within the biomass and photovoltaic programs.

Value of Accomplishment and SERI's Role

The results of these studies would be directly applicable to an integrated receiver design for solar thermal systems which would allow photovoltaic and biomass technologies access to concentrated solar radiation streams at appropriate wavelengths and intensities for direct fuel and chemical and electrical conversion in the receiver. This approach could conceivably double the value of the concentrated sunlight provided by a concentrator field by using as much photon energy as possible before converting the photons to heat and driving thermal processes. SERI possesses the optical technology to develop separator concepts that can operate under high intensity concentrator radiation. In addition, SERI has a major role in the photovoltaic and biomass programs which are developing processes that could be utilized in such a receiver system, eliminating the

need for redundant research. SERI could also lead the development of high intensity photoelectrochemical, photobiological, and photochemical processes which would be compatible with such a receiver as well as continuing the development of high-temperature photothermal processes which had previously been under development by the San Francisco Operations Office of DOE. SERI has the expertise and ability to lead this important program area.

Resource Requirements

It is estimated that funding for this initiative will vary between $2.2 million and $4.0 million annually from FY 1983 through the duration of the planning period.

Active

Low-Cost Concentrating Collectors

Because of the diffuse nature of solar energy, the collector represents a large area and, hence, a large portion of solar system cost. System cost effectiveness may be enhanced by a collector that can provide heat for more than one function such as heating and cooling of a structure and thus provide total space conditioning. In order to meet those heating and cooling needs, the collector must function at temperatures well above those generally developed in flat-plate solar collectors. These temperatures are achieved by evacuated-tube collectors and the compound parabolic-trough collectors that have been studied as part of the active heating and cooling program. Line-focus collector technology, which has been developed for electric power production by the solar thermal program, also offers significant promise for small-scale heating and cooling systems. The cost effectiveness of line-focus collectors increases dramatically as the size and optical performance are reduced, thus a very low-cost line-focus collector, which is smaller in size and has relatively poor optical perfection, can still provide concentrations of 20-30 suns and operate in the range of 100°-200°C with efficiency. The purpose of this initiative is to investigate low-cost line-focus collector systems for active heating and cooling applications based on the concepts pioneered by the solar thermal program. The availability of such collectors to the solar heating and cooling industry could dramatically increase the cost effectiveness of heating and cooling systems.

Objectives and Approach

The purpose of this research is to identify and evaluate advanced types of low-cost concentrating collectors constructed from wood, paper, and other advanced materials that, because of their moisture susceptibility and other technical uncertainties, would not be developed by private industry. This research project would include building and fielding prototype collector arrays in the SERI permanent test facility and evaluating their performance and materials degradation as a function of time. Companion laboratory research studying the effects of moisture expansion and contraction of wood on the optical shape of the concentrator and also similar effects in paper, would be performed to understand the changes observed in field testing. This activity would also allow concepts such as boiling in the receiver tube and heat-transfer phenomena to be evaluated for heating and cooling applications. The approach would involve industry in the preparation of advanced prototype collectors for testing and evaluation.

Value of Accomplishment and SERI's Role

The results obtained by these research activities will lead to advanced line-focusing solar collector systems that have the capability to drive heating and cooling systems for buildings. This research would benefit substantially from SERI's outdoor field testing capability and SERI's materials and thermal research capabilities. If the prototype fabricated by industry prove viable on close scrutiny and long-term testing and evaluation, they could be readily converted to marketable products.

Resource Requirements

It is estimated that funding for this initiative will vary between $0.75 million and $1.15 million annually from FY 1983 through the duration of the planning period. Active initiatives will employ a combined total of approximately 9 to 11 people.

Active

Solar Ponds Research Initiative

Solar ponds represent a very low-cost method for collection and storage of solar energy. This includes both salt-gradient solar ponds and saltless ponds with floating glass or plastic covers to minimize evaporation and heat loss to the atmosphere. Because of their very low potential cost, they have been viewed as a source of heat for building complexes and industrial processes. However, a number of technical barriers must be overcome in order to determine their true potential. Pond fluid dynamics, temperature profiles, and heat and mass extraction are critical research areas that must be well understood for effective operation. In a salt-gradient pond, the process by which both thermal and chemical concentration gradients effect heat and mass transfer requires further study to gain basic scientific understanding. In saltless solar ponds the glazing materials must be studied for not only optical transmission, but biofouling and mechanical damage resistance. Materials of pond construction must also be considered and these include soils and clays as well as polymeric liners that may be needed to prevent salt contamination of adjacent areas. The answers to these and other research questions, including corrosion and thermal-load matching, could provide the basis for the development of a solar pond industry in the United States.

Objectives and Approach

The SERI approach would be to perform basic research in materials, optical properties, and heat- and mass-transfer characteristics of solar ponds. These basic principles would be used to develop and operate research ponds at the SERI permanent facility. The ponds would simulate a variety of heat and mass extraction concepts, as well as support glazing and salt-gradient research. This research activity is presently too risky for commercial ventures to consider. The SERI unified materials, components, and testing approach could lead to advanced concepts for the construction and testing of solar ponds.

Value of Accomplishment and SERI's Role

The results obtained from this research could provide an advanced materials and components technology base for the developing solar pond industry. SERI's current research on low-cost collectors, including flat-plate, line, and point-focus systems, would be used to judge the relative effectiveness of solar ponds and guide research. SERI's expertise in direct contact heat exchange and heat- and mass-extraction equipment developed for the ocean energy program would also support this research activity. If SERI were successful, a broad-based, low-cost pond research program could yield the basis for future industrial solar pond development and deployment.

Resource Requirements

It is estimated that funding for this initiative will vary from $550 thousand to $750 thousand annually from FY 1983 through the duration of the planning period.

Passive

Solid-to-Solid Phase-Change Storage Initiative

A large number of materials that exhibit solid-to-solid phase change characteristics have relatively high heat of transitions (enthalpy of transformation) when undergoing these changes. This heat-of-transition characteristic has potential for storage of solar heat for passive applications since these materials can reversibly absorb a large amount of heat without increasing or decreasing temperature. Pentaerythritol, which exhibits one of the highest heats of transformation, reversibly absorbs about 70 cal/g at 187°C. This temperature is not appropriate for passive applications, but does show the energy potential for this type of material.

Objectives and Approach

SERI would investigate several solid-solid phase change materials for potential applications in direct- and indirect-gain passive systems. This effort would build upon the experience gained in investigating these materials for possible application as thermal buffers for solar cooling systems. Initial studies would focus on alloying pentaerythritol with pentaglycerine to produce materials that operate at temperatures approaching room temperature.

Value of Accomplishment and SERI's Role

The identification of cost-effective solid-solid phase change materials that can be incorporated into passive design, would have a significant impact on the buildings industry. These materials could potentially save much of the mass and associated space, supporting structures, foundations, and cost required for passive heat storage technology.

Resource Requirements

It is estimated that funding for this initiative will vary between $600 thousand and $1.0 million annually from FY 1983 through the duration of the planning period. Passive initiatives will employ a combined total of approximately 9 to 12 people.

Passive

Innovative Window Technology Initiative

Windows represent the critical heat gain and loss component within the shell of most buildings. Industry research is primarily focused on making windows better insulators by increasing the number of panes, adding reflective film, and decreasing infiltration. However, these efforts have not focused on the seasonal performance of these components in passive solar applications. Ideally, the window should reflect heat in the summer, and emit and retain heat in the winter. While additional glazing layers increase insulation, they reduce the amount of solar radiation transmitted through the window for passive heating purposes (approximately 13% loss per pane).

Objectives and Approach

SERI will investigate the following approaches to maximize the seasonal efficiency of windows within the context of passive solar applications: switchable panes with special absorber and reflective coatings, improvement of the basic glass characteristics, and low-conductance gases or vacuums between panes and liquid-crystal applications.

Integral to this effort will be a building systems analysis that will evaluate the cost and performance characteristics of these innovative approaches in various building designs and climates.

Value of Accomplishment and SERI's Role

Improving the passive heating and cooling characteristics of windows could cause a significant reduction (up to 30%) in building energy consumption. This research could stimulate industry to develop and to market improved window products. SERI plans to work in close coordination with the research departments of industrial glass and window manufacturers during this effort.

Resource Requirements

It is estimated that funding for this initiative will vary between $600 thousand and $1.0 million annually from FY 1983 through the duration of the planning period.

SERI

b. Director of Office of Energy Research

The new initiatives described in this section represent areas in which SERI has expertise and unique capabilities. It builds on and expands promising research areas previously described under "Current Programs." In support of the redefined SERI mission, the development of a broader technology base of support is important to the long term success of SERI research programs. Seven initiatives are proposed in the field of Materials Sciences; one initiative in Biological Energy Sciences; two initiatives in Chemical Sciences; and four initiatives in Engineering, Mathematical, and Geosciences.

Materials Sciences

Thermoelectric Materials Initiative

New materials are required to improve materials performance characteristics for thermoelectric energy conversion. SERI's current effort is directed toward the fabrication technologies, but work is needed in materials improvement.

Objectives and Approach

The objective is to prepare, characterize, and study the durability of candidate materials for thermoelectric conversion of low-grade thermal energy. The properties of bismuth-antimony alloys in thin film form will be studied using a novel sample configuration. A sample will be divided into areas each representing a unique composition that will be measured by electron microprobe analysis, atomic absorption spectroscopy, differential reflectrometry and photoacoustic spectroscopy. The properties of these areas will be correlated with material conversion performance and used to determine the basic properties which are important.

Value of Accomplishment & SERI's Role

The results of the study would lead to a better understanding of the basis for optimizing the thermoelectric performance of simple alloy semiconductors, and more specifically the definition of optimum alloy composition, doping, and fabrication processes for the bismuth-antimony system.

Resource Requirements

It is estimated that funding for this initiative will vary from $150 thousand to $270 thousand annually from FY 1983 through the duration of the planning period. Materials Science initiatives will employ a combined total of approximately 7 to 13 people.

Materials Sciences

Neutralization of Low Energy Ions Initiative

The need to elucidate the principal mechanisms of neutralization of low energy ions scattered from solid surfaces is widely recognized and has been the subject of several recent studies. The research would provide a foundation for the physical characterization and mechanisms of degradation of mirror, absorber, photovoltaic, photochemical, and thermoelectric materials.

Objectives and Approach

The object of this study is to investigate the current theories of neutralization and to check their validity experimentally on solid systems of interest to solar energy applications. The plan for carrying out research on the neutralization process is to develop quantitative analysis using low energy ion scattering. The theoretical work will include extension of the formalism to specific systems of interest in solar energy (namely $^{3}He^{+}$, $^{4}He^{+}$, $^{20}Ne^{+}$, and $^{22}Ne^{+}$ on W, Ni, Cu, Zn, Ag, Cd, and Sn). The experimental work will include the acquisition of ion scattering spectra of the above systems over an incident energy range of 1-2 keV.

Value of Accomplishment & SERI's Role

A successful accomplishment of the objective of this research will provide a good quantum-mechanical description of ion neutralization, and then a theory of amorphous films which successfully accounts for the lack of order. Work on multicomponent systems then become practical. This effort will lead to the formulation of techniques applicable not only to solar energy research but to diverse areas of materials characterization and in particular to ion/solid bombardment. Only four other similar low energy ion scattering systems are known to be in use in the United States, and these are not being used for developing quantitative analysis.

Resource Requirements

Funding for this initiative will vary from an estimated $115 thousand to $170 thousand annually from FY 1983 through the duration of the planning period.

Materials Sciences

Low Temperature Metallization by Thermal Decomposition Initiative

Silver metallization is currently used for making mirrors and for providing conductors on photovoltaic cells. However, the mirroring technology uses a wet reduction process that appears to offer limited lifetime for mirrors that are used outdoors. The methods for applying photovoltaic silver metallizations, i.e., vapor deposition and high-temperature thick-film techniques, are, respectively, expensive and require high temperatures, making them incompatible with most of the current generation of advanced photovoltaic materials.

Objectives and Approach

The objective of this study is to investigate the important factors in making particulate inorganic silver compounds, such as silver oxide, that have suitable morphology for deposition onto a substrate and conversion to a silver metallization. The focus of this work will be on preparing suitable powders for deposition and conversion to silver. This will involve studies to understand the reactions that lead to fine particulate formation; to determine the role of the powder morphology using electron microscopy, gas adsorption, etc.; and to investigate the conversion of the silver compounds to silver using thermal analytical techniques.

Value of Accomplishment & SERI's Role

This research can lead to new options for silver metallization in particular, as well as metallization by other inorganic compounds that thermally decompose to the metal. These new metallization options might be particularly important for advanced high reliability mirrors in solar applications and for low-temperature metallization techniques compatible with temperature-sensitive, advanced photovoltaic materials.

Resource Requirements

It is estimated that funding for this initiative will vary between $140 thousand and $260 thousand annually from FY 1983 through the duration of the planning period.

Materials Sciences

New Electrode Materials for Photoelectrochemical Cells Initiative

A major inhibition to the development of photoelectrochemical cells is the lack of electrode materials with sufficiently long lifetime.

Objectives and Approach

Research will be done on new electrode materials that exhibit excellent stability as well as high conversion efficiency. New layered compounds and oxides will be investigated, as well as novel electrode structures such as heterojunctions. The use of photocapacitance measurements to characterize the performance of new materials will be studied, especially with respect to the existence and consequences of surface states.

Value of Accomplishment & SERI's Role

This work if successful, will greatly advance the potential application of photoelectrochemical cells to viable systems that produce electricity and or fuels and chemicals at commercially competitive costs. SERI has unique and proven competence in this research area that enhances the prospects for success.

Resource Requirements

It is estimated that funding for this initiative will vary between $160 thousand and $325 thousand annually from FY 1983 through the duration of the planning period.

Materials Sciences

Theoretical Studies on the Electronic Structures of Semiconductors Initiative

Basic and applied research in theoretical solid-state physics is required to achieve a better fundamental understanding of the different elements constituting a photovoltaic solar cell. Research should lead to understanding interface states, deep traps, surface defects, and surface atomic structures that control device performance; understanding the phenomena associated with pairing of defects, manipulation of barrier heights, passivation, and recombination processes; and characterization of new materials.

Objectives and Approach

The objective of this initiative is to use a quantum mechanics methodology that has been developed to study the fundamental electronic structures of materials that are not only useful for photovoltaic applications but also for a host of other electronic devices. The approach is to study the factors affecting the atomic structure and electronic properties of metal-semiconductor interfaces, to identify factors controlling the Fermi Energy level, and to identify the chemical species that determine the morphology of the interface. The basic models that describe the interelectronic interactions (e.g., correlation) in solids would be improved, and the electronic properties of transition impurities in silicon and III-V semiconductors would be modeled.

Value of Accomplishment & SERI's Role

Considerable time and resources have been spent in the past to develop the methodologies for the sophisticated quantum mechanics calculations required to elucidate the electronic structure of bulk materials surfaces and interfaces of semiconductors. Further refinement and improvement of these techniques will add a wealth of information that will lay the foundations for future breakthroughs in photovoltaics and would complement the more conventional but empirical trial and error method.

Resource Requirements

Funding for this initiative, it is estimated, will vary between $130 thousand and $230 thousand annually from FY 1983 through the duration of the planning period.

Materials Sciences

Nucleation and Growth of Semiconductor Films Initiative

The growth of compound semiconductor thin films such as $CuInSe_2$, CdTe, Cu_2Se, and Zn_3P_2 on foreign substrates is a critical component of developing several new device technologies. This, in part, is due to the need to control the nucleation and film stoichiometry and to doping of compounds which have substantially different vapor pressures among the various chemical species.

Objective and Approach

New growth techniques, such as hot wall vacuum evaporation (HWVE), have shown promise for improving the electronic properties of compound semiconductor layers. Unfortunately, the interplay between the various growth parameters is not well understood. In-situ ellipsometry will be applied to characterize the crystalline structure of the atom layers as they are deposited by HWVE. This technique can be used to characterize the initial growth on foreign substrates in order to optimize the growth parameters for large grain structure films.

Value of Accomplishment

A greater understanding of the mechanisms controlling nucleation and growth of compound semiconductor films on foreign substrates should aid in the achievement of well-structured films with the requisite electrical and optical properties for optoelectronic applications.

Resource Requirements

Funding for this initiative, it is estimated, will be $130 thousand annually from FY 1983 through the duration of the planning period.

Materials Sciences

Superlattice Concepts to Eliminate Dislocation in Semiconductor Heterostructures Initiative

A novel concept involving the use of a superlattice structure in a multijunction high efficiency solar cell to eliminate dislocations has been developed at SERI. However, the mechanism by which the dislocations are eliminated is not well understood. An extensive basic research effort is required to study the mode of propagation of dislocations in a heterostructure and how it affects the cell performance.

Objective and Approach

Under carefully controlled conditions, the dislocation density in a typical heterostructure such as GaAs/$GaAs_{1-x}P_x$ heterostructure can be drastically reduced by incorporating a superlattice band into the structure. The approach taken here would be to fabricate superlattice structures by special CVD and MBE techniques and study the propagation of dislocations by transmission electron microscopy. The concept could be developed to increase the efficiency of cascade-type solar cells.

Value of Accomplishments

A greater understanding of the basic mechanisms of dislocation motion and interaction in semiconductor superlattices and heterolayers will aid the attainment of the above objectives. SERI has in operation the basic crystal growth processes (CVD and MBE) for providing heterolayers for study, and have demonstrated the growth of thin (200A) superlattice crystals.

Resource Requirements

It is estimated that funding for this initiative will vary between $100 thousand and $140 thousand annually from FY 1983 through the duration of the planning period.

Biological Energy Sciences

Microalgae Production of Oils Initiative

Certain microalgae species synthesize hydrocarbons and oily lipid compounds directly from solar energy under special photobiological conditions. However, the metabolism of this process is not well understood.

Objectives and Approach

The objective is to understand and optimize the mechanism for oil production by microalgae species. Research will be done on the photosynthetic reactions (electron transport and carbon metabolism) and on the photosynthetic apparatus (structural and pigment changes) of several oil producing algae under various degrees of nitrogen deficiency.

Value of Accomplishment & SERI's Role

These algae have the potential for being efficient and practical solar energy converters. These studies are necessary for a better understanding of the regulatory mechanism involved in lipid/oil production and accumulation in oil-producing algae. These algae have the potential for being efficient and practical solar energy converters.

Resource Requirements

It is estimated that funding for this initiative will vary between $135 thousand and $295 thousand annually from FY 1983 through the duration of the planning period. This initiative will employ between 1 and 2 persons.

Chemical Sciences

Biomass Electrochemistry Initiative

The conversion of biomass into chemicals is a viable route to replace petroleum-based chemicals with renewable resources. This requires exploration of the routes of conversion of well-defined, biomass-derived compounds into chemicals by electrochemical and photoelectrochemical processes that may be highly efficient. The fundamental questions that must be addressed are electrode materials and catalysis as related to the reactivity of simple, biomass-derived materials and product selectivity. Such data will provide an understanding of the mechanisms of these reactions, which, in turn, may help to design specific syntheses of desired products from biomass-derived starting materials.

Objective and Approach

The objective of this initiative is to understand the electrochemical conversion of well-defined, biomass-derived components into useful chemicals. The approach to be utilized is two-fold. Dark electrolyses of the biomass-derived compounds on a variety of electrode materials will be carried out. The products will be separated and characterized by standard techniques. A correlation between the nature of the products and the electrode materials will be derived, as well as an understanding of the reaction mechanisms. The second approach addresses an exploration of semiconductor electrode materials and electrolytic reactions carried out in the presence of light. Special attention will be given to materials absorbing an appreciable fraction of the solar spectrum and to particulate systems. Examples of the biomass-derived chemicals to be investigated are polyfunctional carboxylic acids such as lactic and levulinic acids.

Value of Accomplishments & SERI's Role

The basic research should lead to a deeper understanding of these types of reactions. This understanding constitutes one of the accomplishments of this new initiative. The second accomplishment is to provide alternative routes, starting with biomass-derived materials, to synthesize chemicals otherwise derived from fossil resources.

Resource Requirements

It is estimated that funding for this initiative will vary between $100 thousand and $140 thousand annually from FY 1983 through the duration of the planning period. Chemical Sciences initiatives will employ one person.

Chemical Sciences

Mechanistic Studies of Primary and Secondary Pyrolysis of Natural Carbonaceous Solids Initiative

Pyrolysis is attendant to most nonbiological thermochemical conversion processes for biomass, peat, and fossil fuel materials. While the engineering of systems for combustion, gasification, liquefaction, and distillation processes are relatively well established, the development of future generations of processes would benefit from a more detailed study, at the molecular level, of pyrolysis pathways. Fundamental work is needed on the mechanism and kinetics of these processes. This information is particularly needed under high-severity cracking conditions and for novel catalytic or gaseous environments.

Objectives and Approach

The objective of the proposed work is to study the behavior of pure components that are primary products of pyrolysis (e.g., levoglucosan from cellulose and 2,5-dimethoxyphenol from lignin). Pyrolysis mechanisms and kinetics at the molecular level will be determined under conditions of time, temperature, environment, etc., to provide a body of chemical information pertinent to the many applied studies currently underway.

The approach to be used combines several pulsed heating techniques, including hot flame gases and resistance heated grids, with direct, real-time, high-pressure, molecular beam sampling into a mass spectrometer. In pulsed pyrolysis into hot flame gases (steam/Ar or He) the sequence of pyrolysis events can be observed and the opportunity for condensation and other secondary reactions is minimized. Secondary pyrolysis events can be followed, however, by varying residence times of primary products in a chosen hot environment.

Value of Accomplishment & SERI's Role

In three years of applied work on the fast pyrolysis of biomass, SERI has developed unique apparatus and experimental approaches to carry out the proposed fundamental studies. Funds for this research would permit a thorough application of the techniques described above to the fundamental pyrolysis chemistry of a variety of mainly oxygenated species of relevance to new and very old biomass. The information obtained is essential to the technical community involved in all biomass and fossil fuels thermal processing. With the capabilities in the SERI laboratories, primary and secondary pyrolysis on the millisecond time scale, at temperatures from 300°-3000° K, is readily observed.

Resource Requirements

It is estimated that funding for this initiative will vary between $115 thousand and $145 thousand annually from FY 1983 through the duration of the planning period.

Engineering, Mathematical, and Geosciences

Stability of Double-Diffusive Processes Initiative

A class of fluid systems termed "double-diffusive" or "thermohaline" exist in which two components of different molecular diffusivity are present and contribute in an opposing manner to the local density gradient. These systems exhibit induced motions that are very different from those predicted on the basis of one component fluid models (which, in contrast, are now well understood). For example, many instabilities can occur in a double-diffusive system even though the net density gradient appears hydrostatically stable. Salt-gradient solar ponds belong to this class of fluid systems and appear to be a suitable and competitive alternative to conventional fuels for the generation of process heat and electricity in regions where salt, land, and low-salinity or fresh water are available. A good understanding of the basic physical phenomena is necessary to determine the long-term performance, operation, and economic competitiveness of such applications.

Objectives and Approach

SERI proposes to perform a coupled theoretical, numerical, and experimental program on fundamental topics of double-diffusive stability, utilizing a laboratory facility which is under construction for the performance of engineering tests on heat and mass extraction from salt-gradient solar ponds. The primary topics to be addressed are stability of non-uniform gradients, selective injection/withdrawal of fluid in a stratified region, and effect of inclined surfaces in a stratified environment. Common to these topics is the need to develop instrumentation suitable to measure the relevant variables in the fluid.

Value of Accomplishment & SERI's Role

The results obtained in these studies will be directly applicable to solar ponds, operation of ocean thermal energy conversion systems, and other energy-related fields such as oil shale extraction, natural gas storage, and transportation.

A laboratory facility directly suited to perform the proposed tests will be completed shortly and the principal investigator has seven years experience in double-diffusive stability research.

Resource Requirements

It is estimated that funding for this initiative will vary between $160 thousand and $300 thousand annually from FY 1983 through the duration of the planning period. Engineering, Mathematical, and Geosciences initiatives will employ a combined total of 6 to 8 people.

SERI

Engineering, Mathematical & Geosciences

Two Phase Flow Heat Transfer Research Initiative

The value of a tubular entrained flow furnace for biomass pyrolysis has been proven in recently completed research at SERI. This type of furnace, used frequently in the petrochemical industry for heating gases and liquids, would be useful for a number of processes in which efficient heating of solid particles is required. Usage of such a furnace is currently limited by a lack of understanding of the heat transfer mechanism in the furnace. Using concentrated solar radiation to heat the entrained particles directly would allow for very effective solar-to-particle heat transfer.

Objectives and Approach

The objective of this effort is to add to our knowledge of transferring heat to dilute gas/solid flows, especially at high temperature. This knowledge will make possible the design of equipment for efficient heating of dilute gas/solid flows. The approach will be to first extend the previous pyrolysis work to allow careful heat transfer measurement in nonreacting dilute gas/solid flows. This work will explore several variables, such as Reynolds number, particle loading, and radiative coupling, and will result in a better understanding of the heat transfer mechanism in pyrolysis. It will lay the groundwork for a full range of parameter studies, thereby expanding applicability of the research results.

Value of Accomplishment & SERI's Role

The results from the research will contribute to the base of knowledge in two-phase flow heat transfer and will support research in a number of energy-related technologies. SERI's personnel and facilities are well equipped to perform the research proposed.

Resource Requirements

It is estimated that funding for this initiative will range from $230 thousand to $260 thousand annually during FY 1983-FY 1985.

Engineering, Mathematical & Geosciences

Direct Contact Heat Transfer Initiative

Organic Rankine cycle engines have been proposed as a method for utilizing low-grade heat to produce electricity. Because of the low efficiency of low temperature power cycles, conventional shell and tube heat exchangers used to preheat and vaporize the organic working fluid comprise a large fraction of the total system cost. The use of direct contact heat exchangers can significantly improve the performance of heat exchangers and thus improve the overall system.

Objectives and Approach

The objective of the proposed task is to understand the fluid mechanics and heat transfer phenomena in a spray tower or packed column direct contact heat exchanger. No methods are currently available for predicting volumetric heat transfer coefficients in a liquid-vapor system. Mathematical models need to be developed to predict the effect of temperature difference relative flow rates, and turbulence on heat transfer performance. Experiments would then be used to confirm the model.

A second related problem is that of flooding in packed and spray tower systems. The correlations presently available for predicting flow regions and maximum possible throughputs in spray columns are being extended to regions for which they have no validity. The proposed research will extend the region of applicability.

Value of Accomplishment & SERI's Role

Development work on direct contact heat exchange has been carried out by the DOE geothermal program, and research on direct contact liquid-liquid heat exchange has been conducted for desalination in Israel. However, the solution of several fundamental fluid dynamics and heat transfer problems would provide the technology that would allow design or scale-up of such devices to be made wtih confidence. SERI has experience in direct contact heat exchange research and has the facilities to perform the proposed work.

Resource Requirements

It is estimated that funding for this initiative will vary between $170 thousand and $295 thousand annually from FY 1983 through the duration of the planning period.

Engineering, Mathematical & Geosciences

Jet Condenser Fluid Dynamics Initiative

The jet condenser power cycle was first proposed for application to geothermal energy sources and further developed for application to ocean thermal energy conversion. These studies analyzed the thermodynamics of the power cycle for these applications and indicated that the cycle has considerable potential for utilization of low-grade heat sources. However, the feasibility of the fluid dynamics of the cycle has never been demonstrated experimentally.

Objectives and Approach

The objective of this work will be to prove the scientific validity of the jet condenser power cycle by performing research on the fluid dynamics of the cycle. The critical elements are the formation of a well-dispersed, two-phase (liquid and vapor) flow of warm water in a converging-diverging nozzle, the performance of the jet condenser in the presence of non-condensibles, and the design of a diffuser to accommodate the cold water jet and the condensed warm water. The approach to determining the scientific feasibility will be to perform experiments using existing equipment.

Concurrently with the experimental work, a mathematical model of a system based on the jet condenser power cycle will be developed and used to analyze the performance of the system under a variety of conditions. This model will be used to determine configurations of the system for application to three scenarios: utilization of industrial process waste heat, geothermal energy, and ocean thermal energy.

Value of Accomplishment & SERI's Role

Thermodynamic analysis of this cycle indicates that it has considerable potential for utilization of low-grade thermal energy. The Second Law efficiency of an idealized jet condenser cycle is approximately twice that of a conventional organic working fluid Rankine cycle. This project should provide evidence of the scientific feasibility of the jet condenser power cycle applied to utilization of process waste heat, geothermal energy and ocean thermal energy. These results should allow an intelligent decision to be made regarding further development of the concept. This project will make use of SERI's heat and mass transfer laboratory which contains a fully instrumented evacuated test cell and warm and cold water supply ideally suited for the proposed experiments.

Resource Requirements

It is estimated that funding for this initiative will vary between $160 thousand and $270 thousand annually from FY 1983 to FY 1986.

B. WORK FOR OTHERS

Contingent upon DOE approval, SERI engages in a number of projects that are sponsored by non-DOE agencies. Many of these agencies face significant energy issues in terms of consumption, cost, or even mission accomplishment. As a result, SERI has the opportunity to use its accomplished staff and specialized facilities to provide timely and economical renewable energy research assistance to these agencies, consonant with or complementary to DOE program goals.

The agencies sponsoring or expected to sponsor work at SERI during FY 1982 are the Department of Defense (Military Services), the Agency for International Development, and the Department of Interior.

U.S. Department of Defense

Background

The Department of Defense (DOD) is the largest single user of energy in the United States and consumes 1.4 quads of energy per year. Within the Federal Government, DOD consumes 80% of the total energy consumed. DOD supports over 1,500 separate military installations worldwide, the electrical power consumption of which ranges from a few kilowatts at remote sites to multi-megawatts at major installations—all totaling 1.2% of the U.S. total electrical demand. DOD also consumes 3% of the total U.S. petroleum demand, and has the responsibility for ensuring the continued flow of oil imports into the United States. The cost of this energy is already staggering and continues to grow. The projected 1982 cost of energy to support the Air Force alone is estimated to exceed $4.5 billion.

In addition to being the largest single consumer in the United States, DOD also has energy requirements that are unique in many respects, including survivability, mobility, reliability, weatherability, self-sufficiency, and scale. These unique aspects, coupled with DOD emphasis on adopting energy technology wherever possible and adapting energy research wherever necessary, can be well served by the experience and unique capabilities of federal research facilities such as SERI. SERI, having unique capabilities and experience in the renewable energy systems research areas, looks forward to a broad program of research support for DOD in the future.

Current Program

SERI has been cooperating with and providing research support to various military services. A summary of current activities is provided.

The Solar Brine Impoundment Pond Design and Evaluation

SERI has been providing research support to the U.S. Army Corps of Engineers to design a solar pond power plant based on brine impoundment ponds in the Red River. This support consists of a conceptual design of a power plant including a pilot solar pond at the Truscott Brine Lake in Texas, and alternative design analyses of the power plant using the same pond but for a baseload, and a peaking, utility-integrated plant.

This project is planned for completion by the end of the first quarter of FY 1982. Total funding is $95,000.

Handbook for Military Engineers

SERI is currently producing a comprehensive Renewable Energy Technology Handbook for Military Engineers for the Department of Defense. This loose-leaf volume will contain 17 separate chapters, addressing different aspects of the various solar technologies and their suitability for military application. The material presented is intended for the military engineer and provides the necessary technical background information to aid in system planning and design. This project is planned for completion by the end of the first quarter of FY 1982. The total funding for this project is $75,000.

New Initiatives

DOD has established a broad spectrum of energy research needs. Against this requirement, SERI is proposing the following specific new research initiatives.

Methanol Fuels Initiative

In order to accomplish its missions, the military depends on a multiplicity of petroleum fuels for its ground power, transportation, and facilities energy requirements. The use of multiple petroleum-based fuels complicates the logistics of fuel supply and storage, continued dependence on foreign fuel supplies, and results in significant fuel costs and annual increases.

Objectives and Approach

The objective of this initiative would be to conduct research related to supporting the adoption of methanol as a single fuel for military ground power, transportation vehicles, and facilities-scale turbine generators.

Value of Accomplishments and SERI's Role

Cooperative research and development of methanol-based ground power, transportation, and facilities energy systems would accomplish the following for DOD and DOE: increase the combustion efficiencies of existing systems significantly; reduce fuel cost significantly (i.e., greater than 50%); simplify logistics; allow for domestic fuel production increases via biomass or coal source methanol production; allow for possible self-sufficiency for some military operations via on-site fuel production; reduce dependency on foreign petroleum supplies; and contribute to mandated national and DOD energy goals.

Participation in this DOD research program by SERI is based on SERI's responsibilities and capabilities in the areas of alcohol fuels research.

Resource Requirements

It is estimated that funding for this initiative will vary between $30 thousand and $600 thousand annually for the duration of the planning period. Department of Defense activities employ one person during FY 1982 and will employ an estimated 6 to 10 people during the remainder of the planning period.

Remote Site Power Requirements Initiative

The military inventory of installations includes two unique categories. The first category includes remote sites, which have power requirements that range from a few kilowatts to 1 MW. These sites operate with equipment that is outdated and in locations that make fuel supply deliveries extremely difficult and expensive (greater than $0.50/kWh). In addition, interruption of fuel supplies can directly affect critical mission accomplishments. As a result, DOD is pursuing the use of energy resources already located at remote sites to provide the majority, if not all the space heating and power requirements. This could be accomplished through the application of new energy recovery and renewable energy technologies.

Objectives and Approach

The objective of this initiative would be to conduct basic and applied research in renewable energy technology areas related to DOD remote site requirements. This would include efforts in resource assessment, unique materials characteristics, low- and mid-temperature solar applications, solar electric power systems, and hybrid systems. SERI would also provide field testing, both at the SERI field test site and at nonremote DOD facilities, of solar systems or components suitable for DOD remote site applications. Work in this area would focus on addressing unique military parameters such as reliability, weatherability, and survivability.

Value of Accomplishments and SERI's Role

Cooperative research and development of renewable energy systems for military remote sites would accomplish the following for DOD and DOE: reduce the conventional fuel requirements of remote sites, both in logistics and costs; improve the energy self-sufficiency of critical remote site missions; reduce dependency on foreign fuel supplies; provide state-side military installations with renewable energy systems and prototype systems; and contribute to mandated national and DOD energy goals.

Participation in this DOD research program by SERI is based on SERI's capabilities in the areas of renewable resource assessment, materials characterization, and system design.

Resource Requirements

Funding for this initiative is estimated to vary between $300 thousand and $550 thousand annually from 1983 through the duration of the planning period.

Advanced Power Systems Initiative

Another unique category of military installations is that of deployable facilities (air-mobile) that are used to support contingency operations. Currently, test deployment of these facilities has documented significant shortcomings in the energy systems associated with these units. In general, the support energy systems have been inefficient, unreliable, and logistically difficult to support (fuel and O&M). In order to ensure that these critical missions are properly supported, an advanced, totally integrated power system capable of operating on multiple fuels (solar insolation plus liquid fuel) must be developed and deployed.

Objectives and Approach

The objective of this initiative would be to conduct basic and applied research in support of an Advanced Military Power System (AMPS) capable of providing the required, reliable energy while using existing energy resources wherever possible. This would include efforts in requirements consolidation, low-cost solar collector technology, combustion technology, and solar electric power systems. Work in these areas would focus on the unique military parameters of mobility, reliability, and survivability. In addition, SERI would also provide field testing of the energy systems or components suitable for military air-mobile applications.

Value of Accomplishments and SERI's Role

Cooperative research and development of renewable energy systems for military deployable facilities would accomplish the following for DOD and DOE: increase the reliability of contingency power systems, reduce the logistical support required by contingency operations, provide dual fuel (solar plus liquid fuel) technology of value to other agencies, and reduce dependency on foreign fuel supplies.

SERI's capabilities in the areas of systems analysis and prototype system design could provide the basis for the commerical production of new mobile power systems.

Resource Requirements

Funding for this initiative is estimated to vary between $100 thousand and $600 thousand annually during FY 1982-FY 1984.

U.S. Agency for International Development

Background

The U.S. government has been providing increasing assistance, in the form of technical expertise, training, and hardware, to the developing and newly industrialized nations of the Third World in renewable energy utilization. This is part of a national effort to lower dependence on imported sources of fossil fuels and reduce worldwide consumption of increasingly scarce fossil fuels. The U.S. Agency for International Development (USAID) will spend, in FY 1982 alone, over $80 million for renewable energy foreign assistance projects. The Department of Energy will continue to manage a number of cooperative research programs (Saudi Arabia, Mexico, Israel) in renewable energy systems. SERI is unique to support these programs.

New Initiative

SERI staff is already familiar with the procedures and practices for international programs, and has had extensive contacts with counterpart scientific research facilities in a number of foreign countries. Against this resource, SERI is proposing a new initiative.

International Research Support Initiative

SERI proposes to provide both basic and applied research support to USAID in the following high priority areas: new and innovative materials (coatings, low-cost absorbers and reflective surfaces); low- and mid-temperature solar applications (solar ponds and linear concentrators); resource assessment (wind and biomass); biomass utilization (gasification and anaerobic digestion); scientific information (exchange and collection); and training (scientific laboratory techniques and procedures). SERI will also provide field testing, both at the SERI field test site and in overseas locations, for solar systems appropriate for developing country applications.

Objectives

The objectives of this work are to facilitate the exchange of scientific information and research data among SERI scientists and foreign scientists working in areas of renewable energy development and utilization; provide for the field-testing and adaptive research of new energy systems, concepts, materials, and techniques with international potential; provide technical support to DOE for international renewable energy cooperative research and development programs; and support U.S. foreign assistance initiatives in renewable energy development and utilization by the provision of technical expertise, energy system hardware, monitoring and resource assessment equipment, and system integration engineering as requested by U.S. government officials.

Value of Accomplishments and SERI's Role

Both SERI and the U.S. governmental agency sponsors will materially benefit from this international reimbursable research initiative. SERI will be able to augment portions of its basic and applied research programs by spreading the cost over several DOE and non-DOE-funded projects. SERI staff will gain valuable field experience, and will be able to funnel the research results of counterpart foreign organizations back into the U.S. domestic research programs. SERI scientists will also gain international exposure and the benefits of collaborative research. The U.S. government will gain the use of SERI's scientific expertise and will be able to more effectively use the existing SERI laboratories, test facilities, and information resources. This will be particularly important in areas such as resource assessment, biomass gasification, photovoltaic-powered water pumping, solar energy information exchange, and low-cost collectors and materials.

Major Decision Points

A planning effort should be initiated to compare and to integrate the projected research needs and objectives of the international reimbursable research and the domestic research programs. This would be an important step toward realizing the most productive relationships between the two programs. This planning function should begin in the second quarter of FY 1982.

Resource Requirements:

It is estimated that funding for this ititiative will vary from $1.0 million to $1.8 million annually for the duration of the planning period.

U.S. Department of the Interior

SERI continues to provide research support to the DOI in designing a combination water desalination and electric power plant using a solar pond energy collection and rejection system. Specific SERI support is provided in developing a test that will provide the design parameters required to specify a direct contact heat exchanger to couple the pond with the power plant thermal cycle. The test will provide data needed to design such heat exchangers for use in plants having up to 50-MWe capacity.

This project was funded with $65,000 in FY 1981 and is funded with $60,000 in FY 1982. SERI expects to continue solar pond research in the future. Specific program content and sponsoring organizations will be established this fiscal year.

SECTION III

PERSONNEL RESOURCES


SERI

SECTION III

PERSONNEL RESOURCES

Present Capability

SERI has assembled the largest staff of accomplished solar scientists and technologists in the world. Sixty-eight percent of the permanent personnel are college graduates, with more than 100 holding doctoral degrees. There are approximately 110 engineers, primarily in the fields of chemical, electrical, mechanical, and metallurgical engineering; 175 physical and life scientists working in the fields of chemistry, physics, and biology; and 21 computer scientists.

There are also approximately 19 guest scientists from both the United States and foreign countries at SERI on assignments for periods ranging from several months to one year or more.

SERI personnel currently assigned to each organizational unit are shown in Fig. III-1.

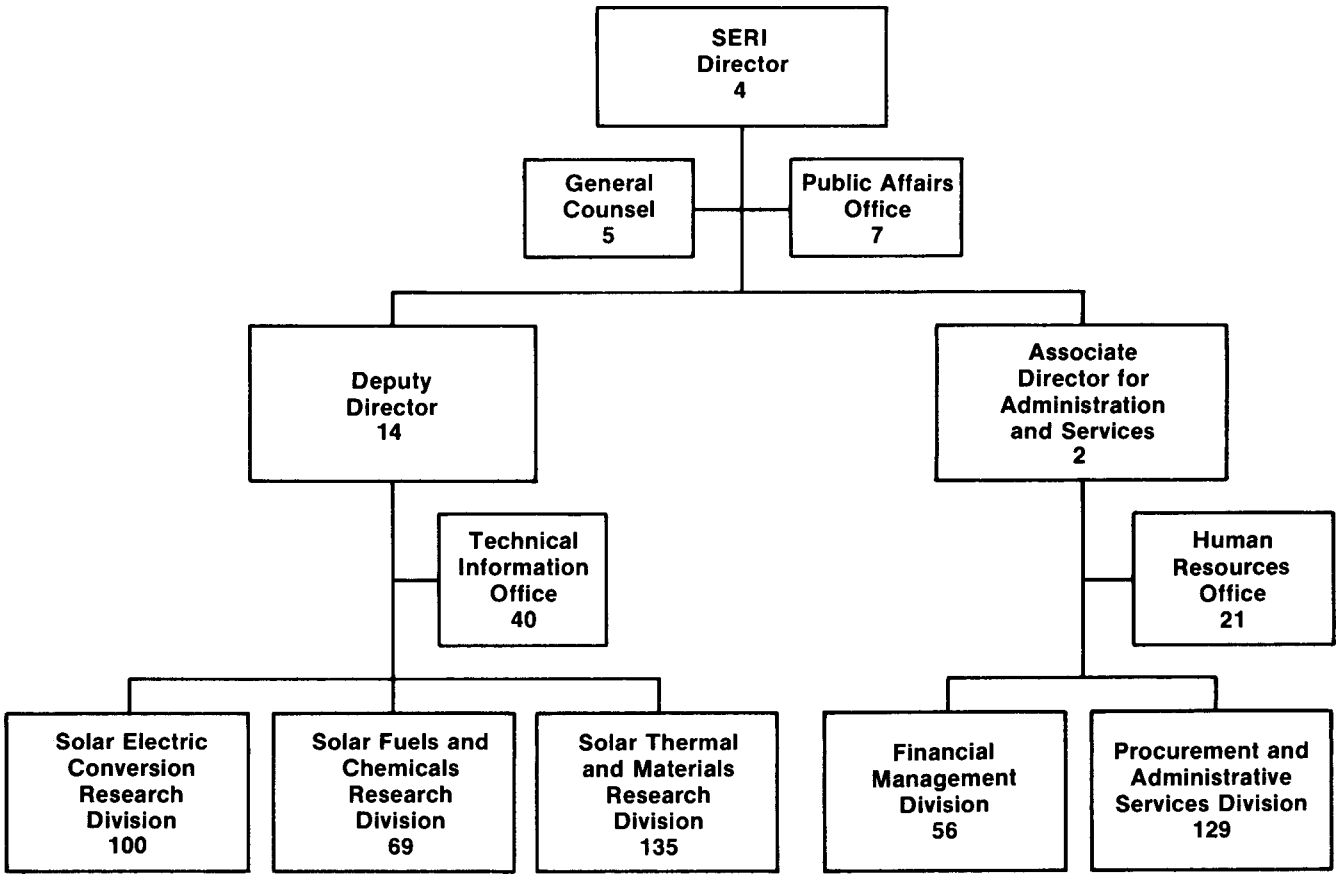
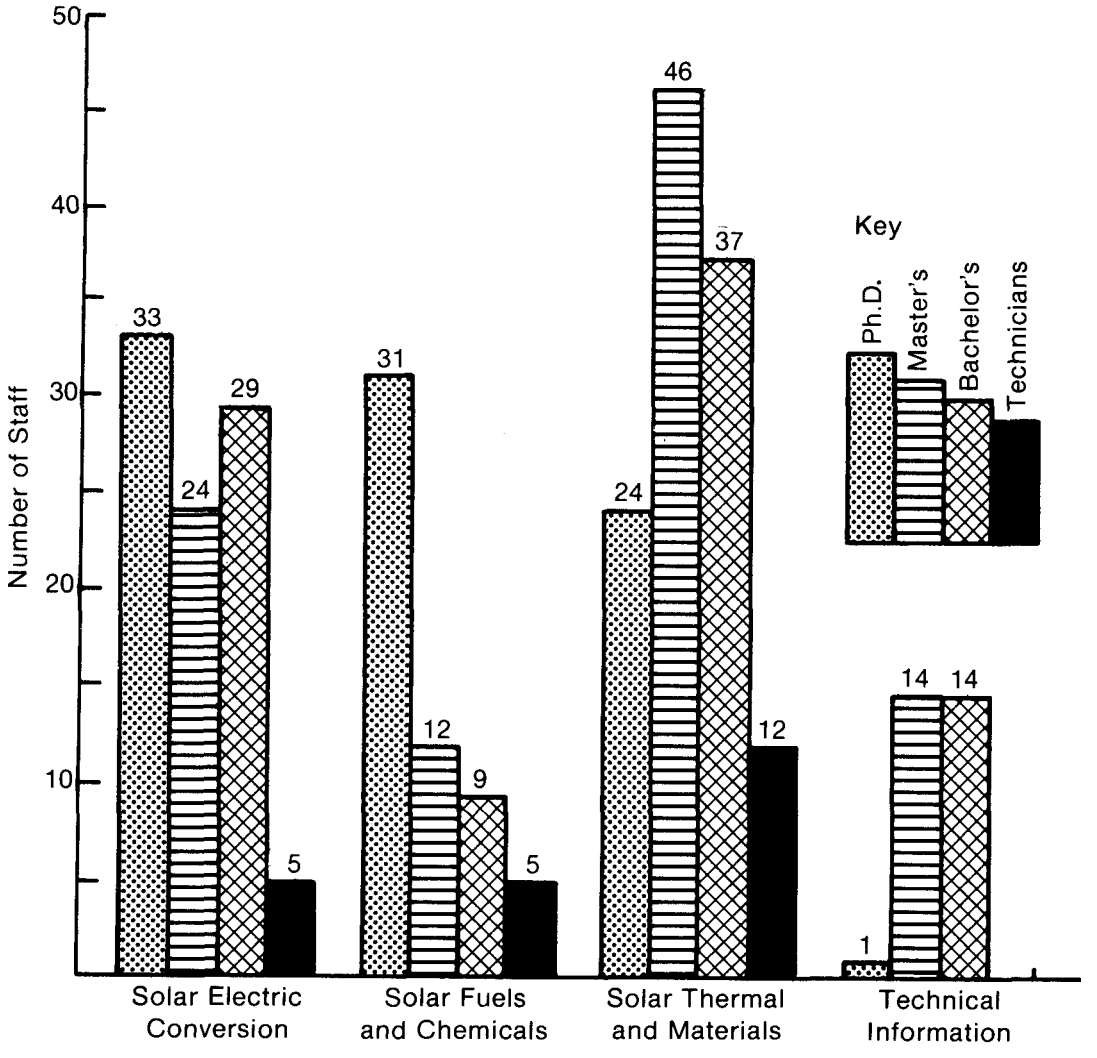


Figure III-1. Current Personnel Assignments

The skill mix associated with SERI's four major research efforts at the beginning of FY 1982 is shown in Fig. III-2. During the planning period, this skill mix should change slightly toward a more senior level of training and experience.



Note: Does not reflect clerical staffs.

Figure III-2. Professional Resources FY 1982

Personnel Trends

Personnel levels at SERI are expected to remain near their present levels over the planning period. This is in marked contrast to the growth experienced in previous years shown in Fig. I-1. The present mix of 70% direct and 30% indirect labor personnel shown in Fig. I-2 will remain relatively constant in the future. Through increased operational efficiency, this ratio should be shifted by 1% per year toward direct labor during the planning period.

With personnel levels beginning to stabilize, increased emphasis will be placed on strengthening SERI's personnel resource. Four specific objectives have been established. The first objective is to strengthen the permanent in-house research capability with an appropriate mix of accomplished emerging scientific talent and senior scientific experience. A major step in this direction was a recent significant reduction in temporary agency personnel combined with a planned increase of approximately 85 scientific positions to strengthen SERI's four major research programs. The majority of this increase will be accomplished by adjusting the present skill mix while keeping the total permanent staff relatively constant.

The second objective is to strengthen management capabilities by further developing the skills of present managers, recruiting seasoned managers with strong research experience to fill vacancies that emerge in the short term, and initiating a strong management development program which will prepare present staff who demonstrate strong management potential to fill future management vacancies. Development efforts will be a combination of formal training programs, self-development, and on-the-job development.

The third objective is to focus special attention on the retention, development, and advancement of present staff members from protected classes. We will continue our commitment to Affirmative Action in filling vacancies, with emphasis on recruiting recent graduates in the technical disciplines; but since the level of total staff is expected to remain relatively constant, considerable emphasis will be placed on internal Affirmative Action efforts.

A fourth objective, which will be implemented in phases over the next five years, is to establish a comprehensive human resource development program to improve productivity, keep pace with technological change, and prepare staff for increased responsibilities. This program will be conducted in a manner similar to the management development program.

Personnel Requirements

As SERI's scientific staff is strengthened in number and experience, the resources of the new Advisory structure will be used to assist recruiting efforts for highly specialized senior research candidates.

While the necessary talents are available in the marketplace, several factors could affect the ability to maintain the present staff and attract new people to SERI. These include the uncertain future of the solar programs administered by DOE, the overall federal funding level for solar research and development, and the possible consolidation of solar programs.

The administration's support for basic and engineering research in a variety of new energy technologies is encouraging. SERI's existing and planned solar research capabilities will serve the program well as a new structure evolves and SERI is prepared to accept more responsibilities in line with its mission.

SECTION IV

SITE AND FACILITIES DEVELOPMENT


SERI

SECTION IV

SITE AND FACILITIES DEVELOPMENT

Introduction

SERI is now housed almost exclusively in leased facilities. Although these facilities are currently adequate, over the long term occupancy of permanent facilities would be more cost-effective and will enhance the accomplishment of SERI's mission. Future facility plans and present facility characteristics and costs are described in the following sections.

SERI Permanent Laboratory and Office Facility

A SERI master plan has been developed to provide laboratories, offices, and associated test areas on an incremental basis. The master plan is consistent with SERI's newly focused mission and future program and staff projections.

The first increment of the plan consists of a Field Experiment Test Area. This facility is designed to house high-bay experiments and associated low-bay laboratories, as well as an assembly/staging area for outdoor experiments. It contains a centralized point for a data acquisition and experiment control system, equipment and storage areas, and related staff offices and support laboratories. The facility will also contain shop areas, a conference room, restrooms, and other support spaces. Construction of the facility will begin during the spring of 1982 and when completed the facility will house approximately 67 employees primarily laboratory researchers. The second increment, if approved by DOE, could be available by 1985 and would provide office and laboratory space for 340 employees. The next two increments that are not presently scheduled could, if necessary, serve a total SERI workforce of approximately 1000 employees.

Laboratory Site Development

Management of the SERI Permanent Facilities project resides with the DOE/SERI Site Office. A site of some 300 acres at South Table Mountain has been obtained from the State of Colorado for the location of a permanent SERI laboratory/office facility. Funding for construction of SERI's permanent facilities is programmed and administered by the DOE/SERI Site Office and is therefore not presented in this plan.

The environmental assessment for the site and SERI's proposed laboratory and office facility was approved by the DOE in May 1980. Necessary access, parking, utilities, and field test facilities are included in the plan.

Present Facilities

SERI is presently leasing approximately 359,000 gross ft^2 in the Denver West Office Complex located off West Colfax Boulevard, Golden, Colo., and in nearby facilities. Figure IV-1 illustrates SERI's present housing in leased space and a phase transition to permanent facilities. During the fall of 1981 a space consolidation plan was implemented to reduce SERI's leased space and consolidate the present operation. Monthly savings

will total approximately $98,000, almost 20% of SERI's current total annual rent costs. This consolidation activity will increase subleased space during the second quarter of FY 1982.

Later in FY 1982 an overall reduction in subleased space occurs due to the release of Denver West Office Building #4. Occupation of the Field Experimental Test Area is shown in FY 1983. After FY 1983, the total space occupied by SERI is projected to remain constant for the remainder of the planning period. Also, subleased space will be eliminated during FY 1985 with the release of Denver West Office Building #18.

SERI has acquired a number of surplus government house trailers. Some of the trailers are test items themselves, and some are used as laboratories and offices. In addition, modular or preengineered buildings have been erected to house field experiments. All structures of this type are now on leased grounds. This space is indicated on Fig. IV-1 as Temporary Space.

In addition, SERI has approximately 11-1/2 acres of field test site space (not shown in Fig. IV-1) under lease. This leased space would be phased out during FY 1982 and FY 1983 as experiments are relocated to the permanent site.

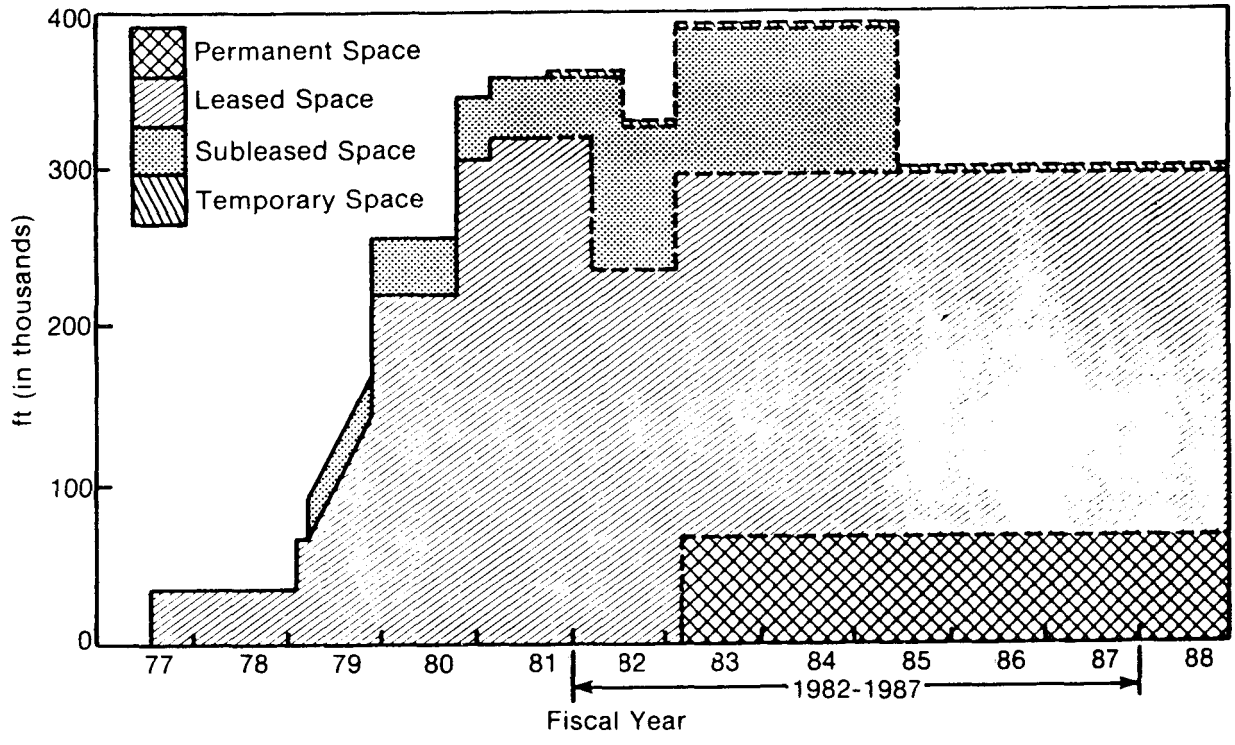


Figure IV-1. SERI Transition to Permanent Facilities

Facility Costs

Rental space was indicated in Fig. IV-1. The cost of rental facilities is indicated in Fig. IV-2. SERI will need to renegotiate office space leases after 1985. A 25% increase in cost can be expected based upon increases in the CPI. The subleased space portion of the total rental cost represents the value of space sublet by SERI to other organizations through FY 1985. The revenue from subleased space fully meets SERI's lease costs for that same space.

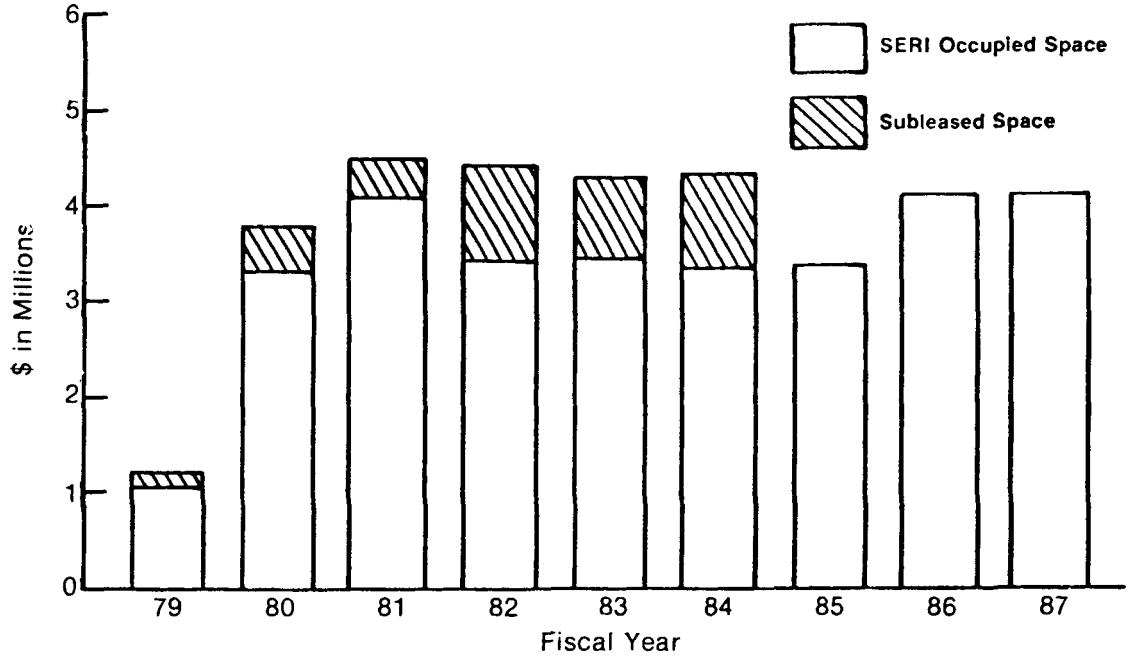


Figure IV-2. Cost of Rental Facilities ($)

Utility costs for the planning period of 1982 through 1987 are projected to range from $500,000 to $800,000 for electricity, $100,000 to $200,000 for natural gas, and $41,000 to $55,000 for water and sewer. Projected real property services are expected to range from $450,000 to $550,000 for this period. Maintenance costs including maintenance, repair and minor new work are projected to range from $650,000 to $690,000 between 1982 and 1987.

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Operated for the
U.S. Department of Energy

January 19
SERI/MR-200-146