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# Research and Exploratory Development Needs in Solar Energy

## An Independent Review for the U.S. Department of Energy

**Solar Energy Research Institute**
A Division of Midwest Research Institute

1536 Cole Boulevard
Golden, Colorado 80401

Operated for the
**U.S. Department of Energy**
under Contract No. EG-77-C-01-4042

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# RESEARCH AND DEVELOPMENT NEEDS IN SOLAR ENERGY

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# PREFACE

This report represents the solar energy portion (less storage considerations) of the comprehensive technology base review being conducted by the Director of the Office of Energy Research, U.S Department of Energy (DOE).

The report summarizes and prioritizes the basic research, applied research and exploratory development needs of the solar energy program identified to date. An estimate of the research monies needed to conduct these tasks during the five year period beginning with FY82 is included.

The current national goal for solar energy is to produce 20% of the total energy consumed in the year 2000 through solar energy conversion.

The Solar Energy Research Institute (SERI) is presently completing for the Deputy Secretary of DOE an in-depth evaluation of the contribution that can be expected over the next two decades from the various solar technologies. The results of that study may affect the prioritization of the research needs identified in this review report.

This report was developed by the SERI staff in response to a request from the Associate Director for Basic Energy Sciences. Input to the report was solicited from other national laboratories engaged in solar research.

E. L. Dowty
Task Leader

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

K. J. Touryan
Deputy Director

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# SECTION 1.0

# INTRODUCTION

### 1.1 BACKGROUND

This report, prepared for the U.S. Department of Energy (DOE) Office of Energy Research, is part of a comprehensive technology base review that the Office is performing for the Department.

The current national solar energy goal is to supply 20% of the total energy consumed in the year 2000. The attainment of this goal, and the continued growth in solar energy conversion to meet the energy requirements of our nation and the world, requires research to complete the maturation of existing and near-term technologies and to identify new concepts. This report identifies specific and general areas of research believed required in this process. The research needs regarding energy storage are excluded from this report and are to be identified in the review report by the Brookhaven National Laboratory.

The report is an independent assessment in that the research needs were identified by solar energy researchers at national laboratories and within the general research community without biases or constraints of current DOE solar program plans and budgets. The needs are not limited to research activities of any particular laboratory or facility but are intended to survey the requirements of the entire field. The report is an update and extension of a previous study completed for the DOE Office of Basic Energy Sciences (Jayadev and Roessner 1980).

The Solar Energy Research Institute (SERI) is presently completing for the Deputy Secretary of DOE an in-depth evaluation of the contribution that can be expected over the next 20 years from the various solar technologies. The results of the evaluation may affect the prioritization of research needs identified in this review report.

The report summarizes and prioritizes the basic research, applied research, and exploratory development needs of solar energy (less storage) that are presently recognized. These categories as defined by DOE are:

- Basic Research. Systematic, fundamental study directed toward fuller scientific knowledge or understanding of subjects bearing on national energy needs; efforts to increase knowledge and quantitative understanding of natural phenomena and environment.
- Applied Research. Systematic study directed toward fuller scientific knowledge for direct use in fulfilling specific energy requirements; the solution of problems in the physical, biological, behavioral, social, and engineering sciences which have no clear-cut applicability to specific projects; includes the technical means of obtaining the knowledge, understanding, and solution.
- Exploratory Development. Efforts guided by the principle that the work should lead ultimately to a particular application or product; the techniques and intrinsic intellectual value of the work may compare favorably with basic research activity; can cut across several scientific disciplines and is intended to explore possible innovation in a particular area of one or more energy technologies.

A funding profile of the research needs for the five-year period beginning with FY82 is included. Not addressed are the substantial efforts needed in technology development through commercialization, production, and operation to meet the 20% goal.

The following sections present the method used to define and prioritize the research needs and the format used to convey the results of this review.

## 1.2 METHOD

Essentially the same methodology was followed in developing this update as was used in the previous work (Jayadev and Roessner 1980). The responsibility for identifying the research needs of each solar energy program element was assigned to qualified SERI researchers. Using the Jayadev and Roessner report, the lead researchers interacted with colleagues at SERI, at other national laboratories, and within the general research community to develop and prioritize the program element's research needs. The lead SERI researchers may have frequently deleted, augmented, or combined the specific recommendations of the individuals polled and considered their own recommendations and opinions at least as heavily as those of their colleagues. "The result is an amalgam of national scientific opinion representing the viewpoints of key researchers in relevant disciplines and of SERI research staff opinions" (Jayadev and Roessner 1980).

Time and resource constraints made a complete representation of solar energy scientists impossible. The report, therefore, should not be considered to represent a national or individual group consensus but rather an approximation of the research community's views on solar energy research needs.

## 1.3 PRIORITIZATION APPROACH

DOE requested a prioritization of the research needs based on (1) the criticality of the particular need to the technical or commercial success of the program element and (2) the usefulness of research in addressing that need. The approach developed by Jayadev and Roessner was followed. The priority levels established and their definitions are:

- Crucial. Work that is essential if progress is to be made in an important area of solar energy; without research on this topic there is little hope of further significant progress in the field.
- Important. Work that is likely to produce immediate payoffs either in improved technology or in scientific understanding of an important solar energy area.
- Needed. Work that has a fair to good chance of helping to further the development of an important solar energy area.

Jayadev and Roessner's report discusses the problem of establishing priorities and the rationale for their selection.

No attempt is made to prioritize research needs among different program elements. The priority levels used imply that the crucial needs of one program element are basically identical in significance. Further, the estimated funding levels may not indicate the potential payback on investment. Some crucial near-term needs may exist that will require considerable investment for relatively small payback in comparison to high-risk important needs with substantial payback if technological breakthroughs are discovered.

## 1.4 FORMAT

The research needs presented in this report essentially follow DOE's solar energy program, subprogram, and program element structure as presented in Table 1. Each chapter is a subprogram topic and contains brief summary statements on its research needs. The needs are prioritized as crucial, important, and needed in the categories of basic research, applied research, and exploratory development. A five-year funding profile beginning with FY82 is included with each summary and pertinent remarks are noted as comments.

The major crosscutting technologies of materials, resource assessment, agriculture, and transportation have been identified as separate program elements. The research topics described in these crosscut summaries were not repeated in the program elements listed in Table 1. However, additional crosscutting technology subjects may be identified within the basic program element summaries. This is an exception to the format requested by DOE, necessitated by their schedule for developing the report. Adherence to the schedule required that the research needs for each program element be identified in parallel and did not allow sufficient time to matrix the four major crosscutting technologies.

Because of the limited environmental/social issues studies identified in the three research categories considered, it was convenient to include these crosscutting needs in the basic program element statements.

A final chapter summarizes the entire program's funding profile.

### Reference

Jayadev, T. S.; Roessner, D., eds. January 1980. Basic Research Needs and Priorities in Solar Energy—Technology Crosscuts for DOE. SERI/TR-351-358. Golden, CO: Solar Energy Research Institute.

**Table 1. SOLAR ENERGY PROGRAM**

| Subprogram | Program Element |
|---|---|
| Solar Building Systems | Building Market Analysis and Development<br>Active Solar Heating and Cooling Systems<br>Passive Solar Heating and Cooling Systems<br>Photovoltaic Systems |
| Solar Industrial Applications | Industrial Market Analysis and Development<br>Process Heat Systems*<br>Biomass Systems (Including Photoconversion and Fuel Production) |
| Solar Power Systems | Utility Market Analysis and Development<br>Solar Thermal Electric Systems*<br>Ocean Systems<br>Wind Systems |
| Alcohol Fuels | Alcohol Fuels Market Analysis<br>Alcohol Fuels Market Development<br>Alcohol Systems Development |
| Solar International | |

*These elements have been combined and are identified as Solar Thermal Systems in the Solar Industrial Applications chapter of this report.

# SECTION 2.0

# SOLAR BUILDING SYSTEMS

SERI

## 2.1 BUILDING MARKET ANALYSIS AND DEVELOPMENT

Market analysis encompasses those studies which establish solar technology cost and performance criteria and focuses upon the nontechnological barriers to their diffusion and adoption. The research goals include:

- identification of existing and potential markets;
- assessment of the current and potential market penetration of solar technologies;
- selection of appropriate solar technologies for intensive development to meet the marketplace needs;
- assessment of the nontechnical barriers to the development and commercialization of solar technologies; and
- development of recommendations to overcome barriers and accelerate solar commercialization (U.S. Department of Energy 1980, p. IV-29).

Market development includes activities intended to accelerate diffusion of conservation and solar technologies by influencing key decision makers in market supply and consumer demand sectors. These activities emphasize near-term solar technologies including domestic hot water systems, low-cost hybrid systems, passive design, active space heating systems, and selected target audiences.

Market development involves the collection and dissemination of cost, performance, and reliability data to those individuals influencing new product development and sales. Market development activities reduce uncertainties that impede market acceptance of solar technologies and seek to develop consumer confidence in new solar products and designs. Market development goals include to:

- collect and disseminate technical, economic, and performance information to current and potential end users and to those influencing commercialization of solar technologies to reduce risks and uncertainties;
- provide training programs to assist industry in entering the active, hybrid, and domestic hot water markets and to develop a qualified work force to install solar equipment and systems;
- accelerate development of quality and performance standards for solar products to provide consumer protection; and
- assist state and local governments to identify and remove barriers impeding the marketing of solar systems (U.S. Department of Energy 1980, p. IV-55).

Since only research activities are discussed, many high-priority market development activities are not presented.

### Basic Research

Market analysis and development is, by definition, an applied field; therefore, it is difficult to distinguish between basic and applied research. Even in the case of research on analytical models, the reason for modifying and improving such models is to develop explanatory and predictive theory to be applied to a specific solar technology in a given setting. Since the basic research category does not match the program element, no recommendations are made.

## Applied Research

Applied research studies potential markets for conservation and solar technologies and develops market strategies for their early commercialization. This involves matching solar technologies to a given market sector end use and setting cost goals for R&D.

Market analysis identifies the nontechnical barriers to commercialization of conservation and solar products and prepares recommendations for government actions to remove those barriers or reduce their impacts.

### Crucial

It is crucial to analyze the factors influencing the market penetration rate and pattern of conservation and solar technologies since RD&D budget allocations and decisions about commercialization strategies rest on predictions of the energy contributions of alternative technologies (Jayadev and Roessner 1980, p. 75). Such studies should incorporate not only the traditional consumer demand, but also the market supply and infrastructure influencing the spread of conservation and solar technologies.

Another crucial area involves analysis of existing governmental actions, ranging from zoning and building codes to loan guarantee programs, on each segment of the building delivery system to determine which no- or low-cost changes will have the greatest potential impact on the rate and pattern of diffusion of solar energy systems and energy conserving practices and design.

A third area involves analysis of the costs and results of conservation and solar retrofits for differing classes of buildings in varying climatic regions of the United States.

A fourth area determines the effect of conventional energy supply economics on the introduction and use of renewable energy technologies. Such studies will determine the impacts of regulation, taxation, and other government policies on the relative market prices of solar technologies; the long-run replacement costs of conventional energy sources and the implications of such costs for solar energy; the market structure of conventional energy supplies; and this structure's effects on market penetration.

It is imperative to identify existing energy end-use requirements, future trends in energy-use patterns, and potential applications of solar technologies in different building classes in various U.S. climatic regions.

Market research must involve assessing solar energy's environmental impacts versus conventional energy sources to determine if solar technologies, in fact, are benign. Such research could help identify and measure the environmental and health consequences of the entire production and consumption cycle of solar technologies and the valuation of their environmental impacts.

Investigating the impacts of existing utility laws (particularly PURPA), regulations, and rate structures upon the economic and social feasibility of solar applications in residential and commerical buildings is necessary.

Finally, it is crucial to analyze the impact and success of the Residential Conservation Service's solar audit program and to investigate the effects of the Building Energy Performance Standards (BEPS) on solar applications in residential and commercial buildings.

### Important

An important area analyzes the residential and commercial retrofit market to determine the replacement potential for existing heating systems with less expensive systems such as heat pumps and wood-burning stoves. In coordination with the retrofit market analysis, the nation's existing residential, commercial, and public building stock should be researched to determine each major building sector's current energy use.

Additionally, an analysis of on-site investments by utilities in conservation and solar technologies should be completed. This analysis should also focus on the advantages and disadvantages of utility financing of conservation and solar applications in various climatic regions for different building classes.

Research must begin to develop energy rating systems so potential home buyers can estimate the energy consumption of new residential construction.

### Needed

Research is needed to develop supply curves for various building classes by demonstrating a spectrum of investment strategies ranging from modest to ambitious retrofits involving a combination of efficiency and solar equipment. In connection with this research, mechanisms are needed for the uniform reporting of retrofitting costs and results for various residential and commercial building types to local code officials, inspectors, utility personnel, local builders, and contractors.

Research focusing upon the question of how individual life styles, or changes in lifestyle, may affect individual energy choices is needed. If it can be shown that significant changes in U.S. social values are likely during the next two decades, then the implications of these changes should be described for individual energy technology choices.

Finally, research is needed on the skilled, semiskilled, and unskilled labor component of dispersed solar applications in various U.S. regions.

## Exploratory Development

This area includes studies that will ultimately lead to particular applications. Exploratory development encompasses social science disciplines including sociology, communication, economics, environmental studies, and policy sciences, and the techniques and intrinsic intellectual value of such work compares favorably with basic technological research activities.

### Crucial

Market penetration estimates suggest that by the year 2000 nearly 25% of the solar energy used will be generated by technologies purchased by individuals rather than supplied by utilities or other centralized sources (U.S. Department of Energy 1979). If the diffusion rate of solar technologies is to increase rapidly, government agencies and the private market sector must understand those factors influencing individual energy choices.

One market analysis goal is to develop theory and simulation models to help explain and predict consumer behavior with respect to alternative energy supplies. To achieve this goal, it is crucial to support research on the consumer decision-making process and the possible tradeoffs among product characteristics including performance, cost, reliability, compatibility, etc., and the influence of risk and uncertainty on consumer decisions. Such research will assess the source, value, and use of solar information in consumer decision making and segment the potential end users of solar technologies in terms of adoption probabilities.

Another crucial research area is the need to develop analytical models to predict the true marginal value of a residential or commercial solar application or conservation investment. Without these models, the building industry may be extremely slow in reacting even to demonstrated solar successes. Predictions from such models will measurably reduce the risk and uncertainty of consumer decision making with respect to solar applications and conservation.

A third area of crucial research includes studies of organizational behavior and decision making. The significance of such research lies in the fact that 75% of the energy generated from solar sources by the year 2000 will be purchased by organizations, ranging from communities to federal, state, and local government units; utilities; and industrial and commercial firms (Jayadev and Roessner 1980, p. 73). Despite their importance, little is known about organizations' decisions to adopt or reject new technological products and processes and about the influencing factors. The overall goal is to develop theory and models that will explain and predict organizational choices with respect to conservation and solar technologies. Such research will assess the significance of organizational and community environments in energy supply decision making.

A final research area is the need to develop theory and models to explain and predict the functional and dysfunctional, direct and indirect, consequences of decisions to adopt or reject conservation and solar technologies. Little attention has been given to consequences because researchers often assume that the adoption of a given technology will produce only beneficial results. However, the agencies supporting conservation and solar technologies should be able to predict the advantages and disadvantages of such innovations before encouraging their widespread adoption (Rogers and Shoemaker 1971, p. 319).

**Important**

One need is to improve the models and procedures for predicting and measuring the social costs and benefits of solar technologies and innovations. Policy decisions should be made based upon the net social benefits associated with policy alternatives. However, current data and approaches to the determination of social costs and benefits are inadequate (Jayadev and Roessner 1980, p. 76). Policy analysis commonly excludes nonmarket costs and benefits that can significantly influence the attractiveness of conservation and solar technologies. The proposed research would develop improved measures of social costs and benefits associated with various policy alternatives.

Another important area is an analysis of the energy policy-making process emphasizing who makes energy policy decisions, the timing of such decisions, and the knowledge requirements. Since public policy on conservation and solar energy is evolving and rapidly changing, analysis of the energy policy-making process is even more important than research in established policy arenas (Jayadev and Roessner 1980, p. 77).

**Needed**

Research is needed to clearly define the roles of various levels of government (i.e., federal, state, and local) in the development and implementation of energy policy. Such research would explore the need for and effectiveness of regional incentives, regulations, and other policy in a decentralized energy economy.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | N/A | | |
| Applied Research | | | | | |
| Crucial | 2,000 | 3,000 | 3,500 | 2,000 | 2,000 |
| Important | 1,000 | 1,500 | 1,500 | 1,000 | 1,000 |
| Needed | 500 | 500 | 1,000 | 1,000 | 500 |
| Subtotal | 3,500 | 5,000 | 6,000 | 4,000 | 3,500 |
| Exploratory Development | | | | | |
| Crucial | 2,500 | 2,500 | 3,000 | 3,000 | 2,500 |
| Important | 1,000 | 1,500 | 2,000 | 2,000 | 1,000 |
| Needed | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| Subtotal | 4,500 | 5,000 | 6,000 | 6,000 | 4,500 |
| TOTAL | 8,000 | 10,000 | 12,000 | 10,000 | 8,000 |

**References**

Jayadev, T. S.; Roessner, D., eds. 1980 (January). Basic Research Needs and Priorities in Solar Energy: Technology Crosscuts for DOE. SERI/TR-351-358. Golden, CO: Solar Energy Research Institute.

Rogers, E. M.; Shoemaker, F. F. 1971. Communication of Innovations: A Cross Cultural Approach. New York: The Free Press of MacMillan.

U.S. Department of Energy. 1980 (January). Solar Energy Program Summary Document FY81. Washington, DC: Assistant Secretary for Conservation and Solar Energy.

U.S. Department of Energy, Council on Materials Science, Division of Materials Science. 1979. Theory of Surfaces. Urbana, IL: University of Illinois.

## 2.2 ACTIVE SOLAR HEATING AND COOLING SYSTEMS

The major objective of the active solar heating and cooling program is the development of practical, reliable, and economically competitive systems for heating water and heating and cooling buildings. This encompasses the residential and commercial building sector. These technological applications include direct water and space heating using air- and liquid-based collection and storage systems; absorption, Rankine-cycle, and desiccant cooling systems; and solar-assisted and ground-source heat pump systems.

The hot water and space heating technologies that use flat-plate or evacuated-tube collectors and sensible storage are at the commercialization stage. Very little basic or applied research is needed except to develop more reliable and lower-cost materials for collectors, storage media, and heat transfer fluids. Although needed, this research is not important for the commercialization of these systems. Exploratory development of plastics for collectors and phase change materials for storage is important to produce a larger market for these systems.

Exploratory development of new absorption and Rankine-cycle systems is important, as is applied research into new working fluids, materials for concentrating collectors, and ground-heat transfer and ground-coupling mechanisms. These technologies are primarily in the development and field testing phase, although a few commercial systems are available. Exploratory development in the areas mentioned is needed to meet the commercialization goals of the program. Heat pumps are commercial items and no research is needed except in areas applicable for solar technologies such as collector and storage materials.

### Basic Research

Basic research is not crucial to the commercialization of active solar heating and cooling systems for buildings. However, basic materials research is needed to develop low-cost and reliable collector and storage materials.

#### Needed

Research into materials degradation mechanisms and adhesion properties will be helpful in developing better collector materials.

### Applied Research

Several research topics related to the solar cooling technologies and one storage technology area that will affect all solar active heating and cooling applications are identified in this category of research.

#### Crucial

Applied research is needed to identify and develop desiccant materials with adsorption properties specifically tailored to solar regenerative cooling. The development of viable desiccant cooling systems depends on this.

Work should be initiated as soon as possible to identify suitable reactions for thermal energy storage subsystems using condensed-phase low-temperature (45-350° F) reversible chemical reactions. The advantages of these reactions are compactness, high storage density, and the elimination of vapor (gas transport piping between containers). After two years, this research should lead to exploratory development of identified reactions.

**Important**

Several materials research areas could further improve solar cooling systems. These include:

- Discovering organic fluids with superior properties to use in Rankine cycles up to 300-400° F. A critical concern is the high-temperature stability of the fluid.
- Researching the properties of fluid mixtures resulting in improved performances of absorption cooling systems using advanced cycles up to 300-400° F.
- Developing phase-change materials suitable for thermal storage in the 250-400° F range.

Research is important in developing better materials for flat-plate and concentrating collectors, which leads to lower cost, higher reliability, and longer lifetimes. Materials consist of absorber materials and coatings, transmissive materials and coatings, and reflective materials and coatings. Heat transport fluids that cost less and are more resistant to degradation are needed for the higher temperature applications. Nondegrading plastics for low-cost and light-weight collectors need to be developed.

## Exploratory Development

Exploratory development activities are necessary in all elements of the active heating and cooling program, especially in the areas of cooling, heat pumps, and energy storage.

**Important**

Several exploratory development areas that are important in improving solar cooling systems include:

- Developing advanced absorption cycles with the potential for higher performance. Important considerations include high-cycle efficiency, low-parasitic pumping power, and lower production costs.
- Developing open-cycle absorption concepts using liquid absorbers.
- Studying the effects of ground-heat transfer and storage coupling for ground-coupled heat-pump systems. Also, developing more effective, lower cost, and more easily installed ground coupling systems.
- Studying the long-term performance of thermochemical heat pumps and storage systems to determine feasibility and cost-effectiveness. A program of full-scale concept testing and development is needed.

- Studying phase-change materials (PCMs) and packaging techniques for both cold and hot latent storage systems. Although several PCM storage technologies are commercially available, not enough is known and further study is necessary for program decisions. Developing reliable and low-cost systems for both heating and cooling applications is the goal.

**Needed**

Further development is recommended for direct-contact heat exchangers using either liquid-liquid, liquid-vapor, or liquid-solid heat transfer. This should increase system efficiencies and lower system costs.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Needed | 500 | 500 | 500 | 500 | 500 |
| Subtotal | 500 | 500 | 500 | 500 | 500 |
| Applied Research | | | | | |
| Crucial | 450 | 550 | 800 | 600 | 600 |
| Important | 1,360 | 1,360 | 1,160 | 860 | 860 |
| Needed | — | — | — | — | — |
| Subtotal | 1,810 | 1,910 | 1,960 | 1,460 | 1,460 |
| Exploratory Development | | | | | |
| Crucial | — | — | — | — | — |
| Important | 1,550 | 1,750 | 1,500 | 1,300 | 1,050 |
| Needed | 250 | 250 | 400 | 400 | 400 |
| Subtotal | 1,800 | 2,000 | 1,900 | 1,700 | 1,450 |
| TOTAL | 4,110 | 4,410 | 4,360 | 3,660 | 3,410 |

**References**

Wahlig, M.; Heitz, A. 1980 (April 23). "Research Needs for Absorption and Rankine Solar Cooling Program Elements." Memorandum to L. Groome, Solar Energy Research Institute.

Peerson, J. J.; Michaels, A. I. 1980 (April). "Recommendations for Technology Improvements and Corresponding Funding Levels for FY82 through FY86 for Selected Areas of the Thermal Energy Storage Program." White paper.

## 2.3 PASSIVE SOLAR HEATING AND COOLING SYSTEMS

The objectives of the Passive Solar Heating and Cooling Systems Program element in basic research, applied research, and exploratory development are:

- Characterize the various environmental resources: sky, atmosphere, and ground effects as well as solar radiation. The data resulting from these studies must be sufficiently accurate and comprehensive to support detailed simulations of the full range of common passive heating and cooling systems across the spectrum of U.S. climates;
- Undertake a preliminary assessment of the potential energy benefits of these environmental resources in absolute terms (i.e., macroclimate effects only) and as limited by natural terrain and the "built" environment (i.e., solar access and microclimate effects);
- Identify the thermophysical properties of materials that would enhance passive system thermal performance and develop new materials with those properties;
- Perform basic heat transfer and fluid mechanics studies to develop the thermal models necessary to support detailed simulations of promising passive heating and cooling systems; and
- Generate, analyze, and test innovative passive heating and cooling system concepts including architectural considerations, HVAC systems integration, and development of rigorous analytical methods to evaluate system performance.

### Basic Research

Basic research involves two areas: (1) environmental resource assessment, and (2) basic heat transfer and energy processes. The first area concerns assessing and characterizing terrestial and atmospheric effects to develop accurate models for system performance calculations. This includes solar radiation, sky properties, atmospheric effects, ground effects, and terrain. The second area involves predicting and verifying passive and integrated system performance.

**Important**

- Studies of ground thermal properties;
- Theoretical models for convective heat transfer within a space and between spaces (interzonal convective transfer);
- New lighting standards based on human requirements and daylight;
- Correlations between irradiation data and illumination;
- More site measurements of solar irradiance on vertical surfaces;
- More accurate methods for generating vertical and tilted surface solar irradiance from horizontal surface solar irradiance;
- Studies of evaporative and convective atmospheric effects on the performance of passive cooling systems;

- Heat transfer coefficients for liquid storage;
- Studies of natural air-flow patterns through ventilated structures and of forced and natural convective transfer through architectural elements used as storage media;
- Studies of stack effects within building plenums and occupied spaces; and
- Studies of heat transfer within air-to-ground and air-to-water heat exchanges.

**Needed**

- More accurate and flexible techniques for predicting the impact of reflective terrain on vertical surface solar irradiance;
- Improved correlations among cloud cover, relative humidity, and sky radiation measurements;
- More detailed models for thermocirculation processes in passive hot water systems; and
- Two-dimensional heat conduction models to be integrated into detailed building energy analysis computer programs.

## Applied Research

Applied research primarily is directed at basic materials development. Materials research has been identified for the following areas: glazings, absorbers/emitters, reflectors, insulation, storage materials, and desiccants. The results should lead to new materials and products that can increase passive system performance.

**Crucial**

- Infrared-transparent materials for use with sky cooling radiators; and
- Selective emitters with properties appropriate for use in radiative sky cooling applications.

**Important**

- Nonmechanical "optical shutter" glazings;
- Inexpensive techniques of encapsulating phase-change materials and ways of organizing these materials into complete storage systems capable of both vertical and horizontal placement; and
- An assessment of existing desiccant materials and identification of need for new material properties.

**Needed**

- Highly insulative materials with high solar transmittance;
- Additives for water that can be used to "fine tune" absorptivity in clear storage containers; and
- A state-of-the-art investigation of surface coatings and finishes that control solar cooling on the building envelope and/or have selective spectral properties.

**Exploratory Development**

Exploratory development is concerned with developing passive/hybrid products and system concepts that maximize the use of the environmental resource for heating, cooling, domestic hot water, and lighting. It also concerns developing analytical methods to evaluate these products and systems under a variety of operating and climatic conditions. The three activities involved are concept generation, system specification, and analytical tool development.

**Crucial**

- Evaluation of the relative merits of plants, ozone generators, and heat exchangers (between outgoing and incoming air) as sources of oxygen for occupied buildings. Comparison on the basis of performance (oxygen level, ion level, impurity content) and cost (back-up energy required);
- Development and/or modification of existing public domain building energy analysis programs to provide simulation capabilities that include the common passive heating and cooling approaches (including daylighting) and that focus on commercial building types; and
- A systematic study of the solar add-on costs associated with the various passive heating and cooling configurations in specific building types.

**Important**

- Structural schemes for shaded roof-aperture systems integrating insulation, reflectors, storage, and structures;
- Schemes for mobile home passive solar retrofit;
- Concepts for integrating photovoltaics with passive heating and cooling systems;
- Configurations for utilizing stack effect for cooling in high-rise buildings;
- Schemes for using nocturnal outside air for cooling in the building envelope and storage mass; and
- Special control logic and control actuator requirements suitable for passive systems.

**Needed**

- Schemes for transferring heat between zones in single and multiple depth N-S zone configurations;
- Schemes for passive preheating and precooling of ventilation air;
- Innovative techniques for keeping direct sunlight off the building envelope in summer; and
- Dehumidifiers, heat pumps, and solar desiccant dryers that could potentially extend the climatic range and occupancy level of passive cooling by handling part of the latent load.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 500 | 500 | 350 | 200 | 200 |
| Important | 1,700 | 1,500 | 1,000 | 750 | 520 |
| Needed | 1,000 | 750 | 600 | 500 | 300 |
| Subtotal | 3,200 | 2,750 | 1,950 | 1,450 | 1,020 |
| Applied Research | | | | | |
| Crucial | 400 | 400 | 750 | 750 | 500 |
| Important | 600 | 500 | 400 | 400 | 350 |
| Needed | 250 | 200 | 200 | 100 | 100 |
| Subtotal | 1,250 | 1,100 | 1,350 | 1,250 | 950 |
| Exploratory Development | | | | | |
| Crucial | 750 | 750 | 750 | 750 | 500 |
| Important | 1,000 | 1,000 | 750 | 750 | 500 |
| Needed | 650 | 650 | 500 | 500 | 400 |
| Subtotal | 2,400 | 2,400 | 2,000 | 2,000 | 1,400 |
| TOTAL | 6,850 | 6,250 | 5,300 | 4,700 | 3,370 |

## 2.4 PHOTOVOLTAIC SYSTEMS

The objective of R&D in the Photovoltaic (PV) System area is to reduce system costs to a competitive level in distributed and centralized grid-connected applications. Goals for the National Photovoltaic Program (U.S. Department of Energy 1979) include the achievement of Commercial Readiness for systems to be used in residential and selected intermediate lead center applications at system prices of \$1.60-\$2.20/$W_p$ in 1986 and central station applications at system prices of \$1.10-\$1.80/$W_p$ in 1990. Corresponding collector prices are \$0.70/$W_p$ and \$0.15-\$0.40/$W_p$, respectively. The former goal is for flat plate and concentrators presently in Technology Development. The latter goal is for materials presently in the Advanced Research and Development Program, primarily Applied Research.

### Basic Research

Most basic research is intended to directly support solar cell development from advanced materials.

### Crucial

These areas include studies of interface phenomena, grain boundaries in polycrystalline semiconductors, and thin-film growth mechanisms and preparation techniques. Insufficient information and understanding of interface phenomena in III-V, II-VI, and II-V compound semiconductors exist and, therefore, a careful study using physical and electrical techniques must be undertaken to explain the role of interface and other defect states which can dominate the electrical behavior of these surfaces. New physical and electrical measurement techniques, which provide useful information about the properties of grain boundaries in III-V and other compound semiconductor materials, should be developed. A general model explaining the electrical activity of grain boundaries in polycrystalline materials and providing insight into the development of effective passivation schemes is needed.

Currently, thin films for use in PV devices are being deposited by numerous techniques, and the best methods are chosen empirically and not from knowledge of fundamental differences in the film-dominated growth mechanisms. In fact, PV performance in some instances may be improved if the nucleation and film growth mechanisms were understood. Therefore, fundamental work is needed on topics such as: (1) investigation of thin-film nucleation mechanisms in deposition techniques (chemical vapor, plasma deposition, hot wall epitaxy, and other currently used methods for growing compound semiconductor thin films on foreign substrates); (2) the substrate's effects on nucleation epitaxy and film growth; (3) what happens physically when films are annealed by various methods (e.g., laser, thermal); and (4) the identification and control of intermediate gas species in plasma deposition.

### Important

Important study areas include fundamental limitations to device performance, local structure of amorphous materials, and new materials identification, characterization, and assessment. Presently, a good consensus exists on calculating a PV device efficiency, given that all material parameters are known (band gap, absorption, photoconductivity, etc.). However, some excitation and transport mechanisms crucial to PV performance (e.g., identification of hole trap centers, charge separation mechanisms, the position of dopants in the lattice) are not well understood, and their understanding should allow, by modification or enhancement, a higher ultimate efficiency.

In amorphous silicon, various theoretical models have been formulated to predict the local structure and bonding patterns of the silicon-hydrogen matrix, but this research is still in the preliminary stage and much remains to be done. Such problems are assuming an increased importance in view of recent research which has shown that not only oxidation and deposition but also the PV cell efficiency itself is critically dependent upon film morphology. Other preliminary work has indicated movement of hydrogen within the amorphous matrix, which might have further consequence for device stability. Further work into such "local" structure models, including bonding configurations, is clearly needed to guide researchers on how to prepare material with the local structure best suited for PV applications.

Measurement of the fundamental electrical and optical properties of new material systems which could potentially be used as active PV collectors and wide band-gap window materials is also important. To determine whether these materials should be investigated for device development, a concurrent theoretical study of the energy band structure and electronic transport parameters is required. Using the measured and estimated electronic material parameters, an assessment of the potential PV performance could be made for the appropriate device structures, and materials for additional research could then be identified.

#### Needed

In this area, studies of non-lattice-matched layer growth have been identified. A new generation of devices is restricted by the inability to achieve high quality layer growth in non-lattice-matched materials, especially III-V compound layer growth on silicon. New structures such as superlattices hold promise but require extensive development. Other considerations such as layer orientation, compositional grading, and defect passivation need investigation.

### Applied Research

Applied research needs are mostly considered crucial. These needs include development of solar cells in such areas as advanced concentrators, photoelectrochemical cells, amorphous silicon, polycrystalline silicon, thin-film gallium arsenide, cadmium sulfide, and other material areas. In addition, some important applied research needs exist in the environmental area.

#### Crucial

Crucial areas include research on junction design and fabrication, research on "contact layer" improvement, studies on the effects of impurities and dopants on material PV performance, research into film characterization techniques, and investigations in various material-specific device development areas.

Many junction configurations (Schottky, P-N, PIN, Heterojunction, MIS) are currently being researched to obtain the highest efficiencies for different materials. However, because of losses due to reflection, inefficient charge separation and collection, and the defined values of the material band gaps, a portion of the energy from the solar spectrum is not utilized. A better physical knowledge of junction performance, along with empirically derived advances in areas such as the optimization of layer thicknesses, graded junctions, back surface reflection, and multilayer devices, has the potential of significantly increasing solar cell efficiencies through improved cell design and fabrication techniques.

In the contact layer area, problems such as good ohmic contacts, low-cost substrates, window layer development, grid structure optimization, and possible encapsulation need careful research to improve the devices' efficiency and stability. In amorphous silicon, for example, the majority of the research has been concentrated on materials and junction development since identified critical problems need to be overcome before reasonable efficiencies can be expected. Consequently, research on contact layers has been neglected and, because of the ultrathin nature of these films, such outer layer fabrication presents a new research area whose technology cannot be directly transferred from other areas such as single-crystal or polycrystalline silicon.

The effects of impurities and dopants on material performance can be illustrated by several examples. Amorphous silicon could not be actively doped and was, therefore, unsuitable for PV devices until the density of states in the gap (a measure of impurity and defect content) was reduced below a threshold level by more careful material preparation. Even so, important questions pertaining to impurity tolerance level, low dopant efficiencies, and the precise role additives play in band-gap tailoring and reducing gap state densities remain unanswered. In the case of $Zn_2P_3$, n-type doping seemed to be precluded by the defect chemistry of the crystal. By finding an appropriate dopant, however, it has been possible to overcome the self-compensation properties of the $Zn_2P_3$ which hindered the fabrication of n-type material. In the CdTe area, it is important to find p- and n-type dopants consistent with good minority carrier lifetimes. General answers to these questions, when applied to many PV material and device configurations, should allow better materials and junctions, and higher solar cell efficiencies.

As PV research proceeds, knowledge of new measurable parameters in material and device characterization becomes increasingly important and will require increasingly sophisticated and sensitive characterization techniques. Typical examples would be density of gap states measurements in amorphous silicon, bonding configurations at grain boundaries, and low impurity level detection. This illustrates the fact that as the PV material gets better, new factors begin to appear which now limit PV efficiencies, since the previous limiting factors have been decreased or eliminated through prior research. Thus, to play its part in solar cell efficiency improvement (materials and devices), a parallel research effort must be maintained in film characterization technique development.

Material-specific areas requiring further research include stability (especially for $CdS/Cu_2S$ cells), semiconductor-electrolyte interface considerations (photoelectrochemical cells), and cell interconnect technologies (tunnel junctions for cascade structure cells).

### Important

This area includes health and safety effects of PV systems (e.g., fire hazards and secondary health and ecological effects of component material production) and ecological and land-use implications of applications in remote areas.

## Exploratory Development

All photovoltaic exploratory development needs are considered crucial.

### Crucial

Exploratory development activities are intended to develop selected advanced PV technologies to demonstrate technical feasibility and economic viability. This is to be accomplished through experimental development of laboratory cells to ensure that they (1) exhibit reproducibility, stability, and size scalability; and (2) meet photovoltaic program efficiency and cost potential goals to enhance advanced material transition from R&D to technology development.

## Funding Requirement

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 3,400 | 3,800 | 4,100 | 3,000 | 3,300 |
| Important | 1,480 | 1,630 | 1,500 | 1,300 | 1,300 |
| Needed | 200 | 200 | — | — | — |
| Subtotal | 5,080 | 5,630 | 5,600 | 4,300 | 4,600 |
| Applied Research | | | | | |
| Crucial | 36,600 | 40,500 | 34,450 | 31,400 | 29,200 |
| Important | 200 | 100 | — | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 36,800 | 40,600 | 34,450 | 31,400 | 29,200 |
| Exploratory Development | | | | | |
| Crucial | 13,200 | 17,400 | 26,200 | 27,700 | 26,500 |
| Important | — | — | — | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 13,200 | 17,400 | 26,200 | 27,700 | 26,500 |
| TOTAL | 55,080 | 63,630 | 66,250 | 63,400 | 60,300 |

## Reference

U.S. Department of Energy. 1979. National Photovoltaic Program Multi-Year Program Plan. DOE/ET-0105-D. Washington, DC: U.S. Department of Energy.

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# SECTION 3.0

# SOLAR INDUSTRIAL APPLICATIONS

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## 3.1 INDUSTRIAL MARKET ANALYSIS AND DEVELOPMENT

This program element establishes a national basis for targeting market development actions and implements marketing actions for the solar technologies that have near-term industrial commercial feasibility. Market analysis determines the industries, end uses, and geographical locations where solar technologies can meet the decision-making criteria in the near, intermediate, or longer term. Market development hastens the widespread use of solar technologies by influencing the key decision-makers in the industrial market that supply and demand equipment and designs or have significant influence over suppliers and purchasers. Market development emphasizes current near-term solar technologies such as direct combustion of biomass and low/medium temperature solar thermal systems. Since the functional categories defined and included in these technology base assessments do not include commercialization efforts, many high priority market development activities are not described.

### Basic Research

According to DOE's definitions of functional categories for the Technology Base Assessment, this category does not match the program element and, therefore, nothing is recommended.

### Applied Research

Several Industrial Market Analysis and Development studies are identified as applied research and described in the following paragraphs.

#### Crucial

Two applied research needs are crucial. One is to complete preliminary analyses of the thermal performance and cost of solar systems for different types of industrial plants based on site visits and assistance from plant personnel. These case studies will determine specific problems of interface between plant end uses and solar technologies that cannot be defined through basic technology research or overview market analyses. Further, this work will clearly define what types of processes are more promising for early solar market applications.

A second applied research effort extends the case studies into market test and applications projects. After market analyses have identified promising solar industrial applications that are most likely to be good performing and cost competitive, alternative system designs by the private sector and construction of several installations should be funded. These installations can be used to stimulate privately funded designs and installations in similar industrial applications. This effort would conclude with a thorough evaluation of its market development success based on technical performance, costs, and whether other plants have considered a similar solar system based on the test market application.

**Important**

Two applied research activities are considered important. To stimulate innovation in solar equipment and system design and supply, government funding is proposed to promote creative thought in the supply sector. A rational cycle would be established to fund prototype development, evaluate the prototype by national labs, redesign and eventually construct and test the revised prototype. This activity would accelerate the development of low cost and high performing solar technologies in the market.

The second area is model development, particularly mathematical models useful for quick yet detailed economic, financial, risk, and system performance analyses. The development and validation of these models are invaluable for market development because of their rapid, accurate evaluation of solar system designs for specific applications.

## Exploratory Development

Several industrial market analysis and development needs of crucial or important priority are identified within the exploratory development category, and are presented in the following paragraphs.

**Crucial**

Three research needs in industrial market analysis and development are apparent. One is to continually investigate near-term markets for all solar technologies applicable to industry. As new technologies become commercially competitive, both technically and economically, this ongoing research will be able to select industries by a four-digit standard industrial code (SIC) and geographical areas where these solar systems are closest to market feasibility. This research will emphasize data development regarding industrial end use requirements, current energy forms and uses, plant locations by types, conventional fuel prices and availability, combustor age by industry and location, government regulations affecting conventional industrial energy use, government incentives, and other market-influencing factors.

A second crucial exploratory development research area in industrial market analysis and development is to complete land-use studies for solar thermal systems in near-term industrial markets. The potential of solar thermal systems is limited by the unobstructed land and roof area available for siting collectors in industrial plants. Through aerial photographs and analysis methods, it is possible to estimate the upper limit of conventional energy displacement by solar thermal systems for specific industries in specific geographical areas.

A third crucial research area is to investigate the potential of solar thermal systems in existing and planned industrial parks. Industrial parks may provide a large market for conservation and solar systems because of intrinsic features of land availablility, compatible needs between different plants, and potentially attractive solar system financing and ownership options. By determining the magnitude, locations, and special problems/ opportunities of the market, generic low-cost solar systems can be designed. These activities will establish the basis for market stimulation actions in industrial parks.

**Important**

Three important research needs for industrial market analysis exist. One is to determine the regional and state compatibility of solar resources, such as biomass, wind, and low-head hydro, with different industries and their locations. This includes determining the magnitude of the resource, understanding the factors that decide the resource costs, and matching the near-term potential resources to industrial locations with congruous end uses.

Evaluating capital financing problems and opportunities are the second important need, particularly for small industrial companies that are more likely to encounter financing problems because of solar systems' inherent high initials costs. This research would determine financing needs, potential sources, and innovative financing options to reduce this impediment in the market.

Finally, policy research is needed to define government options with minimal side effects that stimulate rapid and healthy development of the industrial market. This research will determine administrative and legislative options to the major impediments to widespread solar use in industry, and will evaluate past approaches to these and other analyses problems. This policy research also will develop implementation plans for the more promising policy options.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Applied Research | | | | | |
| Crucial | 1,000 | 4,000 | 2,000 | 1,000 | 1,000 |
| Important | 2,000 | 2,000 | 2,000 | 1,000 | 1,000 |
| Needed | — | — | — | — | — |
| Subtotal | 3,000 | 6,000 | 4,000 | 2,000 | 2,000 |
| Exploratory Development | | | | | |
| Crucial | 4,000 | 3,000 | 2,000 | 2,000 | 1,000 |
| Important | 3,000 | 3,000 | 3,000 | 2,000 | 1,000 |
| Needed | — | — | — | — | — |
| Subtotal | 7,000 | 6,000 | 5,000 | 4,000 | 2,000 |
| TOTAL | 10,000 | 12,000 | 9,000 | 6,000 | 4,000 |

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## 3.2 SOLAR THERMAL SYSTEMS*

Solar thermal systems are evolving through a phased research, development, and application effort assisting U.S. industry in establishing technical and cost readiness. The program is entering a phase involving the implementation of first generation designs in field experiments, commercial production, and pilot plants, in parallel with the development of second generation systems with improved performance and cost benefits. The importance of research within the various program elements has increased as performance and cost requirements of the potential market sectors become more evident. Furthermore, as the first generation systems are deployed both in electrical and industrial process heat applications, new technical and socioeconomic issues are coming to light which require initiation of research in these fields.

Research in solar thermal systems is required in all categories since this technology has stages varying from early conceptual design to commercialization. For the purpose of this document, only those topics are identified that are applicable to Basic Research, Applied Research, and Exploratory Development.

### Basic Research

Basic research is required to increase the scientific knowledge and the quantitative understanding of phenomena in thermal, thermochemical, and materials sciences. The items are categorized in view of their priorities.

#### Crucial

Areas imperative to basic research include:

- an understanding of bonding, compositional, and structural relationships in adhesion;
- improving basic understanding of low- and high-cycle fatigue in solar metallics as a function of temperature;
- elucidating mechanisms of photo-enhanced degradation of polymers and ion transport in solar transmitting materials;
- development of models to correlate polymer materials degradation under environmental exposure; and
- studying enhanced stability/reactivity resulting from interfacial contact between different materials, coatings, and thin films.

*SERI recommends that both electric and direct thermal systems for potential deployment in either utility or industrial process heat market sectors be included in a "Solar Thermal Systems" program element instead of being separated into Process Heat and Solar Thermal Electric Systems.

**Important**

Goals in this area should include:

- improving the understanding of fine particle behavior for ceramic components and how their shape and surface properties affect their rheology and subsequent ceramic or powder metallurgy fabrication;
- improved methods to determine the origin of metal and ceramic flaws and to develop physical techniques for nondestructive detection and measurement of flaws;
- research on fundamental reaction chemistry in gasification and liquefaction in aqueous and nonaqueous media;
- improved understanding of the kinetics of nucleation, phase transformations, and solidification for reproducible metals fabrication;
- studying the use of the visible spectrum in photochemical processes for fuel/ chemical production;
- fundamental studies of the kinetics, temperature regimes, catalysts, and materials compatibilities of thermochemical reactions suitable for solar utilization; and
- studying the use of high heat-flux radiant energy in production of fuels and chemicals.

**Needed**

In basic research, development of nonlinear and stochastic optimization techniques, optical control problems, statistical and time series descriptions of insolation, and improved measurement and prediction capability are required.

**Applied Research**

Applied research is required to increase the scientific knowledge base and to provide directed effort towards the solution of problems in the physical and social sciences without specific project emphasis.

**Crucial**

Goals critical to applied research include:

- a basic understanding and feasibility of cyclic dissociative and recombination schemes for thermochemical transport and storage;
- composite materials research based on polymers and natural fibers;
- matching bio-feedstock to liquid fuel production processes for highest second law efficiency;
- a basic understanding of thermochemical production of hydrogen; and

- an improved understanding of thermoelectric and thermionic processes for adaptation to solar technologies.

**Important**

Successful applied research should include:

- development of high flash point heat transport oils for concentrator systems;
- novel methods of temperature and composition measurements in heterogeneous systems;
- acquisition and evaluation of heat transfer data in gaseous, two-phase, and liquid systems;
- improved understanding of heat transfer phenomena and fluid dynamics processes in solar collector systems encompassing liquid metals, salts, oils, water, and gases;
- prediction and experimental evaluation of convective losses from receiver cavities;
- studying fundamental mechanism methods for enhancing heat transfer to beds of finely divided solids;
- investigation of melting point variation in eutectic mixtures due to decomposition of compounds;
- new formulations of organic reactions mechanisms under extreme thermal fluxes;
- development of stable, low-cost, high-temperature, selective surfaces; and
- development of low-cost, reliable materials for collectors, heat transport, and receiver subsystems.

**Needed**

Areas of significance include to:

- conceive and test theoretical models of atomic forces in adhesion, such as dust on optical surfaces;
- study solar-assisted coal gasification;
- develop materials properties data to assist designing with ceramic materials;
- develop novel measurement techniques, such as rapid determination of field contour and IR methods for thermal loss characterization; and
- explore novel solar collector improvements such as utilization of a "black" fluid, field spray-on reflective surfaces, and all-glass reflector and structure.

**Exploratory Development**

This area is designed to improve the performance and durability of solar thermal systems.

**Crucial**

Goals imperative in this area include development of:

- o low-cost, reliable, durable metalization process for glass and polymers;
- o low-cost, high-optical performance, durable polymer materials and processes for lenses and dome enclosures;
- o salts for use as thermal transport fluids and storage media by understanding thermal transfer, degradation, stability, and compatibility with metals under cyclic operation up to 800°C; and
- o high efficiency, low-cost specialized heat exchangers for solar applications.

**Important**

Successful exploratory development must include:

- o development of long-life and high-efficiency heat engines for operation at 800-1800°C;
- o characterizing heat pipe performance at high tempratures up to 1500°C and understanding material compatibility;
- o fabrication of extruded ceramic reactor/receivers, thin glass material and development of techniques for evaluation of their physical and optical properties;
- o development of solar concentrator systems incorporating in-situ steam generation and in-situ drying processes; and
- o development of advanced solar system/field control technology such as adaptive, continuously updated computer control.

**Needed**

This area requires development of improved high-temperature engine concepts and advanced power conversion equipment based on cycles offering higher thermodynamic efficiencies.

## Funding Requirement

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 1,500 | 2,000 | 2,000 | 1,000 | 1,000 |
| Important | 1,000 | 1,500 | 1,500 | 700 | 700 |
| Needed | 1,000 | 1,000 | 1,000 | 500 | 500 |
| Subtotal | 3,500 | 4,500 | 4,500 | 2,200 | 2,200 |
| Applied Research | | | | | |
| Crucial | 2,000 | 2,000 | 1,500 | 1,000 | 1,000 |
| Important | 1,500 | 1,500 | 1,000 | 1,000 | 500 |
| Needed | 1,000 | 1,000 | 500 | 500 | 300 |
| Subtotal | 4,500 | 4,500 | 3,000 | 2,500 | 1,800 |
| Exploratory Development | | | | | |
| Crucial | 2,000 | 2,000 | 1,500 | 1,500 | 1,000 |
| Important | 2,000 | 2,000 | 1,000 | 1,000 | 1,000 |
| Needed | 1,500 | 1,500 | 1,000 | 1,000 | 500 |
| Subtotal | 5,500 | 5,500 | 3,500 | 3,500 | 2,500 |
| TOTAL | 13,500 | 14,500 | 11,000 | 8,200 | 6,500 |

## Comments

The information provided in this section addresses process heat systems and solar thermal electric systems. SERI recommends this program element be named Solar Thermal Systems, which combines the Process Heat Systems and Solar Thermal Electric Systems elements shown in the DOE outline of the Solar Energy Program. This single element should be included within the Solar Industrial Applications subprogram. Reference to it should be made in the Solar Power Systems subprogram.

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## 3.3 BIOMASS SYSTEMS (Including Photoconversion and Fuel Production)

Our nation has a vast renewable energy resource in existing and potential biomass. These resources include forests; farm crops such as corn, sorghum, and grasses; and the potential of aquatic crops in the ocean and inland. Objectives of the biomass systems program element include biomass production and conversion to energy or energy-containing chemicals.

Several practical methods already are available to produce and utilize biomass. However, basic and applied research is necessary to find the most effective systems to utilize solar energy through biomass. These studies need not impede the immediate utilization of biomass.

Some of the research listed is completely applicable to and needed for the production of ethyl alcohol. These items are listed here and in the chapter, "Alcohol Systems." Recommended budgets for these items are not duplicated but divided equally between the two areas.

### Basic Research

Biomass systems topics which are in the basic research category include:

#### Crucial

- Biomass Production, Bioconversion, and Extraction
  - Develop plant biochemistry for the efficient production of chemicals from plants (including unconventional crops).
- Thermal Conversion of Biomass
  - Study slow and fast pyrolysis;
  - Research fundamental reaction chemistry in liquefaction in aqueous and non-aqueous media; and
  - Research electrochemical biomass processing.
- Thermochemical and Thermoelectrochemical Conversion of Solar Energy
  - Demonstrate the feasibility of cyclic, dissociative, or N-fixing schemes; and
  - Study modified electrodes and electrocatalysis.
- Photochemical Conversion and Storage of Solar Energy
  - Define photophysical and photochemical parameters of photosensitizers required for efficient capture and primary conversion of solar quanta; and
  - Synthesize and characterize redox catalysts capable of serving as photosensitizers and stable intermediates in sequential electron-transfer events.

- Photoelectrochemical Energy Conversion
  - Develop models and theoretical understanding of photoelectrochemical cells and charge transfer across semiconductor-electrolyte interfaces.
- Photobiological Conversion of Solar Energy
  - Develop primary processes and electron transport mechanisms in photobiological processes.

**Important**

- Biomass Production, Bioconversion, and Extraction
  - Investigate mechanism of action of cellulose-degrading enzymes; and
  - Define mechanism of action of xylanases.
- Thermal Conversion of Biomass
  - Develop new formulations of organic reaction mechanisms under extreme thermal or photo fluxes.
- Thermochemical and Thermoelectrochemical Conversion of Solar Energy
  - Acquire and critically evaluate thermodynamic data;
  - Search for new solid electrolyte anion, cation, and gas conductors; and
  - Microscopically describe ionic and electronic processes at solid/electrolyte interfaces.
- Photochemical Conversion and Storage
  - Develop accurate and quantitative theories for predicting molecular properties.
- Photoelectrochemical Energy Conversion
  - Study new and novel photoelectrochemical reactions such as $CO_2$ and $N_2$ reduction and alternative anodic processes to $O_2$ evolution.
- Photobiological Conversion of Solar Energy
  - Study the stability of biological systems for photoconversion; and
  - Study the metabolism of biological systems including $N_2$ and $H_2$ metabolic processes, $CO_2$ fixation, and photorespiration.

**Needed**

- Biomass Production, Bioconversion, and Extraction
  - Investigate rheological properties of biomass slurries.

**Applied Research**

Biomass systems topics which are in the applied research category include:

**Crucial**

- Biomass Production, Bioconversion, and Extraction
  - Agronomically improve yields of biomass by induction treatments and plant genetics;
  - Investigate pretreatment with chemicals to make cellulose and hemicellulose more accessible to hydrolytic agents;
  - Develop hybrid microbial strains with enhanced biosynthetic capability using genetic engineering;
  - Increase energy efficiency of fermentation product recovery by improving existing separation processes and developing novel separation processes;
  - Study microbial production of chemicals; and
  - Research immobilized microbial cells.
- Thermal Conversion of Biomass
  - Produce thermodynamic, thermophysical, and optical property information on biomass and chars; and
  - Develop catalysts for gasification and liquefaction.
- Thermochemical and Thermoelectrochemical Conversion of Solar Energy
  - Demonstrate thermally regenerable EMF cell cycles.
- Photochemical Conversion and Storage
  - Match spectroscopic, photophysical, electrochemical, structural, and catalytic properties of photosensitizers and redox catalysts in heterogeneous media to effect useful photochemical reactions, such as water splitting and reducing $N_2$ or $CO_2$.

**Important**

- Biomass Production, Bioconversion, and Extraction
  - Develop plants with desired qualities for biomass using tissue culture;
  - Improve process control of fermentation; and
  - Study pentose metabolism to improve chemical production from biomass.
- Thermal Conversion of Biomass
  - Perform kinetics study of secondary cracking of primary pyrolysis products; and
  - Demonstrate novel thermal processing methods (e.g., molten salts, microwave).
- Thermochemical and Thermoelectric Conversion of Solar Energy
  - Study reversible chemical systems for heat transport and storage.

- Photochemical Conversion and Storage of Solar Energy
  - Study mechanisms of direct and sensitized photoisomerization reactions for unimolecular storage and develop specific catalysts for the reverse processes.
- Photoelectrochemical Energy Conversion
  - Develop new semiconductor electrode materials and structures, new electrolytes, and compatible redox couples that promote the stability of high efficiency photoelectrochemical cells;
  - Study the toxicology and environmental effects of potentially hazardous and toxic materials under consideration for photoelectrochemical cells; and
  - Study catalytic effects on semiconductor electrodes and their relationship to electrode overvoltage.

**Needed**

- Thermochemical and Thermoelectrochemical Conversion of Solar Energy
  - Study novel high-temperature dissociated gas separation techniques.
- Photochemical Conversion and Storage
  - Develop new instrumentation and new techniques.
- Photobiological Conversion of Solar Energy
  - Study, in vitro, systems containing isolated biological components in cellfree, energy-converting systems.

**Exploratory Development**

Biomass systems studies which are in the exploratory development category include:

**Crucial**

- Biomass Production, Bioconversion, and Extraction
  - Engineer novel bioreactors to improve fermentation technology; and
  - Manipulate biosynthetic pathways to tailor microorganisms to produce selected chemicals.
- Thermal Conversion of Biomass
  - Characterize environmentally hazardous conversion by-products.
- Photobiological Conversion of Solar Energy
  - Study hydrogen production using photosynthetic bacteria; and
  - Study hydrocarbon and oil production using green algae.

**Important**

- Biomass Production, Bioconversion, and Extraction
  - Investigate microbial and enzyme conversion of hemicellulose to chemicals of commercial importance;
  - Study marine microorganisms by investigating their potential as chemical producers; and
  - Investigate higher plant production of chemicals.
- Thermal Conversion of Biomass
  - Develop novel methods of temperature and composition measurement in heterogeneous systems; and
  - Investigate prototype reactors.
- Thermochemical and Thermoelectrochemical Conversion of Solar Energy
  - Discover new solar-driven processes in metallurgy and biomass gasification.
- Photoelectrochemical Energy Conversion
  - Study photoelectrochemical reactions produced by particulate systems (photochemical diodes).

**Needed**

- Biomass Production, Bioconversion, and Extraction
  - Study Lignin bioconversion to produce chemicals of commercial importance.
- Thermochemical and Thermoelectrochemical Conversion of Solar Energy
  - Study solar-assisted gasification of coal; and
  - Research the use of $ZrO_2$ in the high-temperature electrolysis of steam, $CO_2$.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 6,650 | 7,315 | 8,046 | 8,850 | 9,735 |
| Important | 3,200 | 3,520 | 3,872 | 4,260 | 4,685 |
| Needed | 100 | 110 | 121 | 135 | 145 |
| Subtotal | 9,950 | 10,945 | 12,039 | 13,245 | 14,565 |
| Applied Research | | | | | |
| Crucial | 9,550 | 10,500 | 11,555 | 12,711 | 13,982 |
| Important | 3,150 | 3,465 | 3,811 | 4,190 | 4,615 |
| Needed | 700 | 720 | 847 | 930 | 1,025 |
| Subtotal | 13,400 | 14,685 | 16,213 | 17,831 | 19,622 |
| Exploratory Development | | | | | |
| Crucial | 2,500 | 2,750 | 3,025 | 3,327 | 3,660 |
| Important | 3,150 | 3,465 | 3,811 | 4,190 | 4,615 |
| Needed | 1,000 | 1,100 | 1,210 | 1,350 | 1,450 |
| Subtotal | 6,650 | 7,315 | 8,045 | 8,867 | 9,725 |
| TOTAL | 30,000 | 32,945 | 36,297 | 39,943 | 43,912 |

# SECTION 4.0

# SOLAR POWER SYSTEMS

## 4.1 UTILITY MARKET ANALYSIS AND DEVELOPMENT

The objective of this program element is to accelerate the introduction of renewable energy resources into the electric and gas utility supply systems. The basic and applied research requirements of this element revolve around fundamental resource data base needs and analytic methods development in contrast to the application of these tools in the engineering development, demonstration, and commercialization phases. An assumption underlying the utility market analysis and development program element is that the various renewable technologies are presently under development. This program element defines the impacts of the technologies on the utility sector and the requirements that the technologies will have to meet for penetration of the utility sector.

### Basic Research

The basic research needs of this program element are primarily in the resource assessment area. In determining the impact of solar technologies on utilities, little effort has been focused on the effects of resource transients. This is due, in part, to an insufficient resource data base.

**Important**

- Continued recording and data reduction of short-time interval (minute-based) wind and insolation transients;
- Correlation of transients over large areas, such as two wind clusters spaced 100 miles apart; and
- Development of multiyear time-correlated data from multiple sites on an hourly basis (both wind and insolation).
- Analysis of likely bioresource fluctuations within given resource areas, seasonally and yearly

**Needed**

- Better wind-shear data for application to a single large WECS; and
- Transient output of a large WECS array.

### Applied Research

The applied research needs of this program element are primarily method or analysis tool development. Present methods alone are inadequate for determining the impacts of solar technologies on the utility systems. The following methods and assessments should be developed.

**Important**

- A method of optimal investment evaluation, given risk and uncertainty. Investments must include both central station solar plants and investments in dispersed applications for the customer;

- A method to determine the output of an array of wind machines; and
- A method to determine the potential impacts on the utility of large utilizations of SHAC technologies.

**Needed**

- Assessments of the impact of government tax and regulatory policy on energy production and consumption patterns, and, in particular, on decisions to invest in new energy technologies; and
- A method to statistically accommodate the appliance usage patterns of individual load centers.
- Assessment of the bioresource/utility requirements interface.

**Exploratory Development**

The exploratory development needs of this program element are few. Acceleration of solar technologies into the utility sector requires that some efforts be focused on innovative methods development. Efforts should be undertaken to explore the possibility of applying analysis techniques currently used in other disciplines to the solar/utility interface.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| Needed | 300 | 300 | 300 | 300 | 300 |
| Subtotal | 1,300 | 1,300 | 1,300 | 1,300 | 1,300 |
| Applied Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | 700 | 500 | 500 | 500 | 500 |
| Needed | 300 | 200 | 200 | 200 | 200 |
| Subtotal | 1,000 | 700 | 700 | 700 | 700 |
| Exploratory Development | | | | | |
| Crucial | — | — | — | — | — |
| Important | 50 | 50 | 50 | 50 | 50 |
| Needed | — | — | — | — | — |
| Subtotal | 50 | 50 | 50 | 50 | 50 |
| TOTAL | 2,350 | 2,050 | 2,050 | 2,050 | 2,050 |

## 4.2 OCEAN SYSTEMS

The Ocean Systems Program is developing methods of extracting and distributing significant amounts of energy from the ocean in a reliable, environmentally acceptable, and cost-effective manner. The methods presently under consideration include ocean thermal energy conversion (OTEC), extraction of energy from waves and currents, and conversion of the energy stored in ocean salinity gradients. A full-scale, closed-cycle OTEC power plant is being built to demonstrate the economic and environmental feasibility of extracting energy from the ocean. Open Claude-cycle OTEC power plants are in the final stages of technological development and soon will enter the engineering phase. The Claude cycle may represent a second generation improvement on the closed-cycle OTEC. In parallel with this main effort, hydraulic-cycle OTEC concepts are being explored and the technology of methods which extract power from waves and currents is being developed. Previous studies have indicated that the technology for extracting usable energy from the ocean salinity gradients is not yet suitable for development.

The primary near-term goals are to successfully complete the demonstration project and to provide a cost-effective alternative to the closed-cycle OTEC through the successful development of a Claude-cycle OTEC. These goals recognize that the fundamental technology of closed- and Claude-cycle OTEC power plants has been developed beyond the research and exploratory development phases. The secondary goals are to continue the exploratory development of hydraulic-cycle OTEC power plants and the technology development of extracting energy from waves and currents. The exploratory development of hydraulic cycles is presently hampered by a lack of basic knowledge about specialized areas of fluid mechanics. The development of systems to extract power from waves and currents is presently hampered by a lack of practical and cost-effective ideas based on known physical phenomena. This area represents fertile ground for the inventor rather than the researcher.

The near-term goals for development concentrate on those systems beyond the research and exploratory development phases except for hydraulic cycles. The ultimate cost-effectiveness depends on the development of low-cost materials, innovative construction techniques, improvements in the understanding of certain aspects of fluid mechanics, the behavior of the coupled ocean/atmosphere, and methods of storing and transporting energy that can only be recognized through an aggressive research program. The development of other energy systems, such as those based on salinity gradients, awaits further increases in the basic understanding of relevant physical processes. The presented research agenda addresses itself to this technology, which may succeed the systems currently under development, and to cost reduction, through new materials and processes, of the technology now under development. Potential long-term operating problems, such as impact on the environment, are addressed.

### Basic Research

Basic research aims at a fuller understanding of certain fluid mechanics areas, the behavior of the ocean and its interaction with the atmosphere, the response of the coupled ocean and atmosphere to perturbations, and the behavior of certain materials.

#### Crucial

No basic research needs have been identified that are presently deemed crucial.

### Important

The basic research areas considered important are:

- Modeling of the worldwide response of the coupled ocean and atmosphere to the extraction of thermal or kinetic energy from the ocean as well as changes in the distribution of dissolved gases and chemicals.
- The flow characteristics and physical properties of low temperature (35-80°F) and low pressure (0.1-0.5 psia), two-phase (water vapor and liquid) mixtures.
- The variability and anisotropic character of ocean wave spectra, particularly near shore, needs better characterization.
- A better characterization of the chemistry and dissolved gas content of ocean waters; e.g., the concentration of free ions, dissolved $CO_2$, and nitrogen needs to be determined as a function of location and depth.
- Understanding microscopic marine organism growth on metal and polymeric materials under conditions of water flow and low pressure needs to be increased.

### Needed

The basic research areas considered necessary are:

- An increased understanding of the mechanisms controlling evaporation and condensation of water. Bulk processes (nucleation of vapor pockets or liquid drops) and surface process should be considered.
- An increased understanding of the electro-hydrodynamic behavior of sea water including charge transport by free ions in sea water and the charging of drops of sea water during formation.

## Applied Research

The primary need is applied research in materials and processes leading to improved cost effectiveness. By combining improved knowledge of the medium in which the system operates with improved materials, new concepts may be developed for accomplishing the functions critical to energy extraction from the sea.

### Crucial

The applied research topics considered crucial are:

- Modeling the response of particular aspects of the ocean to the extraction of thermal and kinetic energy; e.g., the response of the Gulf Stream, the Kuroshio current, or the Gulf of Mexico.
- Modeling the response of the ocean shores to a removal of wave energy; e.g., the effect on beach erosion or tidal estuaries.

- Developing methods to characterize the actual worldwide environmental impact of ocean energy systems, particularly the development of remote sensing methods that could quickly cover a large area when deployed on an airplane or satellite.
- An increased understanding of ways to safely store and transport energy through chemical reactions, particularly those which lend themselves to later release of the energy in a controlled, environmentally acceptable manner.
- Developing lighter-weight, stronger, and low-cost materials to satisfy structural and heat transfer requirements in the ocean environment. These include research on light weight composite materials suitable for turbine blades; corrosion resistant low-cost materials suitable for heat exchangers; and strong, easily formed materials suitable for platform hulls.

**Important**

The applied research areas considered important are:

- Economic studies of the relative value of fresh water versus energy in markets which might be supplied by OTEC systems.
- Data on the behavior of different diameter drops (0.1-5.0 mm) of water colliding at low pressure (0.1-0.5 psia) in an atmosphere of water vapor with relative velocities ranging from 0-10 m/sec; particularly the probability of bouncing, coalescence, and break-up as a function of drop diameter and relative velocity.
- Data development on the flow of two-phase (water vapor and liquid) mixtures through nozzles at low temperatures (35-80°F) and pressure (0.1-0.5 psia); especially delineating conditions under which the bulk nucleation of vapor pockets, the growth and eventual bursting of these pockets, and the formation of shocks will occur.
- Data and theory development for heat and mass transport between different liquid-flow geometries by evaporation and condensation under OTEC conditions.
- Modeling and data on the hydrodynamic/structural aspects of the interaction of the ocean with floating, semisubmerged, and submerged bodies, particularly research on systems for which structural elements are in mechanical resonance with the hydrodynamic forcing.
- An increased understanding of the structural, transport properties, and strength of osmotic or dialytic membranes.
- An increased understanding of the bonding and adhesion of materials to withstand vibration and thermal stresses. For example, the bonding of thermoelectric materials to heat exchanger substrates.

**Needed**

The applied research topics considered necessary are:

- Data and theoretical models for the flow of a liquid through a complex distribution system, particularly flow through narrow, multibranching passageways or through pipes with a large loss of mass from slots or nozzles in the pipe.

- Data and theoretical models for nonlinear waves on the surface of a liquid, particularly the parameters which control mode of wave breaking.
- Data development on the biological effects of artificial upwelling of seawater from ocean depths, particularly to determine if a commercial mariculture can be supported by the effluent from an OTEC plant and what the economic significance of this product would be.

## Exploratory Development

While the feasibility and potential for ocean energy can be demonstrated with the current technology, full commercialization will be realized through the introduction of new, improved systems initiated by an aggressive exploratory development program.

### Crucial

Exploratory development of these concepts is considered crucial:

- Innovation in the area of new hydraulic-cycle concepts is considered crucial.
- Development of a convincing argument, based on data and theoretical models, that the proposed Mist Lift cycle is feasible.

### Important

Exploratory development of these concepts is considered important:

- Exploratory development of the inverse vapor compression power cycle based on the transfer of vapor between low and high salinity flows of water.
- Exploratory development of new concepts for extraction and conversion of the ocean energy resource which minimize the need for physical structure or moving parts; e.g., direct conversion concepts based on magnetohydrodynamics or the thermoelectric effect.
- Application of existing concepts to other energy resources available at sea, such as geothermal sources of hot water.
- Innovative concepts for storing and transporting energy in an economical and safe manner.
- Further development of methods using hydrogen to produce electricity or as a fuel for producing mechanical work.

### Needed

The concepts needing exploratory development are:

- The pressure retarded osmosis power cycle that uses the osmotic pressure across a membrane separating a reservoir of low salinity from one of high salinity to produce power.

- The inverse electrodialysis power cycle (sometimes called the dialytic battery), especially an investigation of the use of its internal electrical currents for electrolytic processes.
- Platform, moving, and ocean engineering concepts suitable for application with alternate ocean energy systems.
- Innovative concepts for the use of tides, not necessarily as direct generators of power, but perhaps as a mechanism for dredging harbors (controlled erosion).

## Funding Requirement

| 1980 Dollars in Thousands | FY82 | FY83 | FY84 | FY85 | FY86 |
|---|---|---|---|---|---|
| Basic Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | 450 | 600 | 800 | 600 | — |
| Needed | — | — | — | — | — |
| Subtotal | 450 | 600 | 800 | 600 | — |
| Applied Research | | | | | |
| Crucial | 400 | 400 | 450 | 500 | 500 |
| Important | 850 | 900 | 1,000 | 700 | — |
| Needed | 75 | 100 | 100 | — | — |
| Subtotal | 1,325 | 1,400 | 1,550 | 1,200 | 500 |
| Exploratory Development | | | | | |
| Crucial | 300 | 300 | — | — | — |
| Important | 650 | 800 | 700 | — | — |
| Needed | — | — | — | 250 | — |
| Subtotal | 1,100 | 1,300 | 950 | 250 | — |
| TOTAL | 2,875 | 3,300 | 3,300 | 2,050 | 500 |

## Comments

The BES program does not address the research needs of the Ocean Systems Program. With the exception of some work funded in thermoelectric conversion, no projects exist which enhance the understanding of sea operation or provide guidance for the development- and testing-related projects. At a very minimum, a clearinghouse for relevant ocean research conducted by other agencies should be created. Preferably, all or most of the research identified in this report should be initiated.

The environmental research appears to be more adequate, although most of the program needs are met with program funds.

## 4.3 WIND SYSTEMS

The objective of this program element is to accelerate the development and commercial use of reliable and economically viable wind energy systems. A significant technology and engineering effort has been maintained during the 1970s which culminated in large-scale experimental projects (MOD-OAs and MOD-1). Problems associated with the operation of wind systems are already being resolved as a result of this effort. Therefore, basic research will not have a major impact in meeting this program element's objective. Applied research and exploratory development, however, can possibly reduce the cost of energy in the years ahead.

### Basic Research

Basic research consists of fundamental studies directed toward improved scientific knowledge on wind and wind systems. The studies will be in three general areas: (1) wind characterization, (2) conversion techniques, and (3) general converter technology.

#### Needed

Research in these three areas is needed because of their long term potential for reducing energy cost. The first area consists of some meterological studies of wind characteristics as well as some fundamental fluid dynamic research. The second area relates to the processes for converting wind energy into other energy forms, such as mechanical and electrical. Although many conversion techniques can be considered, the most significant process utilizes the concept of lift in which a force is exerted on a moving airfoil and effectively converts wind energy to mechanical energy. Of course, the mechanical energy then can be converted into other energy forms. In the third area, fundamental studies on the converter could include structural dynamics, aeromechanics, and material properties, especially fatigue.

Of the $750K recommended for basic research each year, several grants could be funded in these areas.

### Applied Research

Applied research consists of systematic studies directed toward improved scientific knowledge that is supportive of wind system projects. Assuming that the applied research in conversion techniques other than lift devices will be minimal (while realizing that applied research for alternate conversion techniques may arise as a result of basic research efforts), the major efforts will be devoted to studies of wind characteristics and conventional wind turbines.

#### Important

Important research topics in the wind characteristics area are: wind resource assessments, development of siting techniques, and wind variability studies. More specifically these studies will provide information on the magnitude and distribution of the wind resource, on appropriate methods of sitings, and on wind gusts that may affect turbine durability, performance, and operation strategy. The work applies to economics, siting, design, performance, and operation of wind turbines.

Studies for conventional wind turbines should include the development and validation of general analysis and design techniques. Included are methods for performance prediction (operational factors), methods for utility integration, and design methods for vibration and rotor dynamics. Currently such studies have been carried out by manufacturers or designers. As a result, in many cases they have come too late and have not been shared with other designers. In addition to analysis, testing facilities are needed. For example, NASA LeRC has proposed to establish a structures laboratory at Plumbrook, Ohio. This facility will permit fatigue testing of major structural components, primarily blades, for both large and small wind turbines.

All of these efforts are important, but as wind systems will be in the commercialization, production, and operations phase between FY82 and FY86, the applied research effort should be relatively modest. Except for FY82, the suggested funding level is $4.5 million. An additional $2 million in FY82 will provide testing equipment for the NASA LeRC structures laboratory.

## Exploratory Development

Exploratory development is directed towards a particular application or product that has the potential for increased performance and/or reduced cost. It is a vitally important activity which permits the implementation of ideas and techniques for reducing and simplifying the material and equipment requirements of wind energy systems.

### Crucial

Exploratory development is crucial in FY82 to FY86 as DOE provides support to industry to reduce the cost of energy in 10-20% increments. Examples of exploratory development projects are single bladed wind turbines, innovative blade materials, innovative tower design, two-speed operation, control studies and variable pitch blade tips. An example in the wind characteristics area would be forecasting techniques. Studies in manufacturing techniques and in quality control trade-off as well as the development of standardized costing methods also are appropriate subjects.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | — | — | — | — | — |
| Needed | 750 | 750 | 750 | 750 | 750 |
| Subtotal | 750 | 750 | 750 | 750 | 750 |
| Applied Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | 6,500 | 4,500 | 4,500 | 4,500 | 4,500 |
| Needed | — | — | — | — | — |
| Subtotal | 6,500 | 4,500 | 4,500 | 4,500 | 4,500 |
| Exploratory Development | | | | | |
| Crucial | 13,000 | 15,000 | 17,000 | 17,000 | 15,000 |
| Important | — | — | — | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 13,000 | 15,000 | 17,000 | 17,000 | 15,000 |
| TOTAL | 20,250 | 20,250 | 22,250 | 22,250 | 20,250 |

**Comments**

The Basic Energy Sciences (BES) support comes from material sciences, engineering, and mathematics. Exploratory development, such as NASA-LeRC efforts to develop low cost blades from fiberglass or wood, has already benefited from BES support. However, as noted earlier, basic techniques, knowledge, and understanding are still needed. BES can contribute significantly to this.

Environmental research has been following the technological and engineering development efforts. Television interference was identified in the mid-70s as a potentially serious problem for wind turbines. Noise was studied briefly soon thereafter; aesthetics and pollution studies also have been funded. A more comprehensive approach, however, is needed to place environmental problems in the perspective required for commercialization, production and operation of wind systems in FY82 to FY86. Much must be done to avoid surprises arising from inadequate siting or incomplete environmental research studies.

# SECTION 5.0

# ALCOHOL FUELS

SERI

## 5.1 ALCOHOL FUELS MARKET ANALYSIS

This category of research analyzes the economics and marketing forces that affect the production and use of alcohol fuels. Included in this analysis are the impacts on the agricultural sector of increasing the proportion of agricultural output directed to nonfood uses and the apportionment of the costs among these end uses. Other major areas of research include the environmental effects of more intensive use of the land for crop production and the social impacts of possible changes in agricultural structure, particularly marketing distribution systems, that such a program might precipitate. Policy analysis addresses the need to coordinate agricultural and energy policies. One of the basic tool-building areas that should be an integral part of a future research program is the economics of converting feedstocks to alcohol and other products.

### Basic Research

This is a relatively small component of the overall research program. As mentioned above, the major purpose is to fill in the gaps of economic theory in multiproduct firms and processes.

**Important**

Developing internally consistent models of firm behavior in the production of multiple outputs from multiple inputs is necessary to analyze alternative processes and products from biomass.

### Applied Research

Most of the required economic and market analysis is considered to be applied research. At least one explanatory or predictive theory exists for most questions of interest in the field. What remains is to formulate questions that yield useful and interesting answers that anticipate rather than follow the needs of both policy makers and business people.

**Crucial**

Imprecise measures commonly are used to estimate the amount of biomass that is potentially available for conversion to alcohol and other products. Knowledge of resource characteristics, including land and water availability and type is not precise nor well defined at the national level. This research effort should be a multiyear, major commitment so that quantitative and qualitative knowledge needed for effective policy is obtained and made available.

An assessment of the potential biomass resource base should be coupled with an environmental research program. Some biomass production schemes introduce potential environmental problem areas. Consequently, some biomass resources may never become widely available because of environmental concerns.

**Important**

Projects necessary for a well-rounded and useful biomass research program include the economics of alternative conversion processes, the social impacts of increased production in rural areas, and the potential uses of alcohol fuels on farms and in blends with other fuels. Analysis and recommendations for unified energy and agricultural policies will complement these activities. Some research and planning for international activities should be considered an integral part of this effort.

The social impacts and policy analysis tasks presume that the production of energy in the agricultural sector will lead to structural changes in agriculture, rural life, and goals of farmers. This will necessitate a different view of agriculture and energy policies that have been largely distinct up to now.

If alcohol fuels derived from agricultural biomass are to be successful on a large scale, their production and distribution will have to be coordinated with existing marketing channels for food and fiber products. Therefore, it is important to understand the present market structure of agriculture and how alcohol fuels may complement or conflict with this system. A study of potential uses of alcohol fuels must consider the trade-off among local (rural) uses of the fuels and other uses, such as blends and petrochemical substitution. Much of this work will be tied to the economics of conversion concerning the versatility of the processes and the products that will be coming from the biomass refinery.

**Needed**

Although international studies should be an integral part of the important alcohol fuels' studies, it likely will receive insufficient attention.

As a result, several international studies may be useful. Assessing the potential of the poor, sugar-producing nations for alcohol fuel production and examining innovative agricultural schemes is a project that should be performed.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | 500 | 500 | 500 | 500 | 500 |
| Needed | — | — | — | — | — |
| Subtotal | 500 | 500 | 500 | 500 | 500 |
| Applied Research | | | | | |
| Crucial | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| Important | 750 | 750 | 750 | 750 | 750 |
| Needed | 500 | 500 | 500 | 500 | 500 |
| Subtotal | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 |
| Exploratory Development | | | N/A | | |
| TOTAL | 2,750 | 2,750 | 2,750 | 2,750 | 2,750 |

## 5.2 ALCOHOL FUELS MARKET DEVELOPMENT

Projects under the heading of market development are not research projects in the academic sense, but rather are characterized by marketing research, product description, and outreach/extension activities. The major needs in the outreach activity are establishing programs to disseminate the results of market analysis and technical research. For marketing and product research, the major needs are to assist technical researchers in identifying promising product lines for the energy and nonenergy outputs of alcohol and biomass refineries.

### Basic Research

Very little basic research is relevant to market development activities since, by definition, this program element is applications-oriented. However, basic research on the theory and practice of technology transfer and diffusion of innovation is crucial if market development programs are to be successful. There is considerable applied research on this topic, but basic research is needed to understand the process of technology adoption as it relates to new energy supplies and applications in agriculture.

### Applied Research

Applied research that relates to alcohol fuels market development includes topics that are crucial and important.

#### Crucial

The highest priority research is to develop an effective outreach and extension capability. Institutions that perform the bulk of the research in a specific area should house this capability. Eventually, this should be linked to existing organizations such as agricultural and energy extension services. Familiarity with the agriculture industry and related associations will be a long-term activity that is necessary to maintain the outreach and extension capability.

#### Important

A multiyear task that integrates the needs and desires of the users of biomass fuel, chemical, and feed products with the results of applied research will be useful in maintaining the overall coherence of the program. Market and product research often helps investigators make the product more relevant to the needs and resources that exist in a given situation. This is particularly true in the area of the nonfuel outputs of a biomass refining operation.

### Exploratory Development

This category is not considered to be relevant since market development activities involve specific applications.

## Funding Requirement

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 250 | 250 | 250 | 250 | 250 |
| Important | — | — | — | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 250 | 250 | 250 | 250 | 250 |
| Applied Research | | | | | |
| Crucial | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| Important | 500 | 500 | 500 | 500 | 500 |
| Needed | — | — | — | — | — |
| Subtotal | 3,500 | 3,500 | 3,500 | 3,500 | 3,500 |
| Exploratory Development | N/A | N/A | N/A | N/A | N/A |
| TOTAL | 3,750 | 3,750 | 3,750 | 3,750 | 3,750 |

## 5.3 ALCOHOL SYSTEMS DEVELOPMENT

Alcohol is now an attractive alternative liquid fuel and President Carter has established a national goal of a half billion gallon production capacity by 1980. This amount of production requires a substantial research program to develop less costly biomass resources convertible to alcohol and to seek out less expensive conversion and separation techniques.

Most of the recommended research areas are generally applicable to biomass and are discussed in that chapter. Budget recommendations have not been duplicated but are split equally between the two chapters.

### Basic Research

The basic research studies for the development of alcohol systems should include the following items.

#### Crucial

- Biochemistry and development of plants for the efficient production of desired products (including unconventional crops); and
- Membrane biochemistry related to improving tolerance of microorganisms to fermentation products.

#### Important

Understanding the mechanism of action of cellulose-degrading enzymes and xylanases is important to alcohol system development.

#### Needed

Rheological properties of biomass slurries should be investigated.

### Applied Research

Applied research areas requiring investigation for the development of alcohol systems include:

#### Crucial

- Agronomical development (including plant genetics) to improve biomass yields;
- Plant physiology to improve biomass yields;
- Biological pretreatment to make cellulose and hemicellulose more accessible to microorganisms and enzymes;
- Chemical pretreatment to make cellulose and hemicellulose more accessible to hydrolytic agents;

- Strain development (including genetic engineering) to develop hybrid microbial strains with enhanced biosynthetic capability;
- Improved energy efficiency of fermentation product recovery by improving existing separations processes and developing novel separations processes;
- Immobilized microbial cell research; and
- Microbial production of chemicals.

**Important**

- Tissue culture to develop plants with desirable qualities for biomass energy systems;
- Research to improve fermentations process control; and
- Studies of pentose metabolism to improve biomass use for chemicals production.

**Exploratory Development**

Areas requiring exploratory development include:

**Crucial**

- Novel bioreactor engineering to improve fermentation technology; and
- Biosynthetic pathway manipulation to tailor microorganisms for the production of selected chemicals.

**Important**

- Investigating microbial and enzyme conversion of hemicellulose to chemicals of commercial importance; and
- Biochemical and genetic studies of marine microorganisms for investigating their potential as chemical producers.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 700 | 720 | 847 | 930 | 1,025 |
| Important | 650 | 715 | 786 | 864 | 950 |
| Needed | 100 | 110 | 121 | 135 | 145 |
| Subtotal | 1,450 | 1,545 | 1,754 | 1,929 | 2,120 |
| Applied Research | | | | | |
| Crucial | 4,150 | 4,565 | 5,020 | 5,520 | 6,075 |
| Important | 450 | 495 | 544 | 600 | 660 |
| Needed | — | — | — | — | — |
| Subtotal | 4,600 | 5,060 | 5,564 | 6,120 | 6,735 |
| Exploratory Development | | | | | |
| Crucial | 1,000 | 1,100 | 1,210 | 1,350 | 1,450 |
| Important | 650 | 715 | 786 | 864 | 950 |
| Needed | — | — | — | — | — |
| Subtotal | 1,650 | 1,815 | 1,996 | 2,214 | 2,400 |
| TOTAL | 7,700 | 8,420 | 9,314 | 10,263 | 11,255 |

SERI

# SECTION 6.0

# SOLAR INTERNATIONAL

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Many activities beneficial to the international effort and the overall U.S. solar community cannot be categorized as basic research, applied research, or exploratory development, yet they do embrace and crosscut these activities. For this reason, Solar International program element study areas have been identified which are recognized as being required even though they may not fit precisely into the strict definitions of these categories. It is hoped that they will be included in these categories because of the uniqueness of Solar International.

The present Solar International activities are comparable to the United States' program in the 1970s in that the greatest need is for planning a coherent global effort in renewable energy technologies and for gathering pertinent information to establish the potential of these applications.

The purpose of this assessment is, therefore, to outline strategies crucial to the technical and commercial success of solar energy development in foreign countries. This involves global planning studies, adaptation of existing technologies, modification of solar systems, and a determination of the infrastructure necessary to support widespread application. Presently, no basic research studies have been identified, and the classification of those listed as either applied research or exploratory development is somewhat arbitrary.

It is important to note that the relatively low funding profile estimated for this element is based on the assumption that considerable personnel resources and support systems, such as computer services, will be obtained from the foreign countries involved in the studies.

## Applied Research

Topics categorized as applied reasearch in the Solar International program include:

### Crucial

Global Resource Assessment: This area concerns establishing the local availability of renewable resources such as insolation, wind, hydropower, and biomass (principally wood, crop residues, and human and animal wastes). Current information is not available in any comprehensive fashion but is spread across many publications. This information must be assembled for international users. Portable, inexpensive, and relatively simple monitoring stations should be developed after identifying the relevant parameters to be monitored, so that additional data can be collected in those countries requiring more adequate coverage. This baseline data is needed before U.S. solar technology can be effectively transported abroad.

(Estimated funding requirements: $490,000. This estimated funding is necessary to successfully implement this study. Portions may come from other U.S. agencies, while the purchase cost of the monitoring stations may be provided by the interested countries. Enumerators to survey the potential biomass resource must be provided by the individual countries.)

Controlled Environment Agriculture: This effort will supplement the U.S. solar greenhouse program. The study will entail: materials study on glazing suitable for hot and dusty climates; analytical, numerical, and experimental studies leading to better understanding of heat and mass transfer relationships; investigation of incorporating various passive features to reduce heating and especially cooling loads for use in foreign countries.

(Estimated funding requirements: $400,000.)

Crop Drying: The few fundamental studies on crop dryers performed in the United States must be complemented by analytical and numerical studies leading toward a better understanding of heat and mass transfer in various dryers suitable to be manufactured by U.S. companies for deployment in other countries, especially in Asia, Africa, and Latin America. These dryer studies must be coupled with additional analytical and numerical efforts to gain a better understanding of the transient thermal response of various crops (useful to the United States and foreign countries) under solar dryer conditions.

(Estimated funding requirements: $230,000.)

**Important**

Refrigeration: This area emphasizes analytical, numerical, and experimental studies leading to better understanding of passive refrigeration systems with substantially reduced cooling loads, suitable for use in the United States and most foreign countries.

(Estimated funding requirements: $220,000.)

Solar Collectors for Industrial Process Heat: This area will perform critical materials analysis of seals, covers, and selective surfaces for solar collectors and will complement the U.S. research effort on selective surface deposition techniques by investigating selective and highly absorbing paints that can be applied directly to locally available materials.

(Estimated funding requirements: $240,000.)

Solar Ponds: Materials research is needed to develop soil treatment techniques which will inhibit seepage of hot salty brines into the soil to eliminate synthetic liners in remote, arid regions.

(Estimated funding requirements: $180,000.)

**Exploratory Development**

Topics categorized as exploratory development in the Solar International program include:

**Crucial**

Digesters: This study will complement the U.S. research effort on semi-centralized or large farm-size processing plants by investigating small digesters built with less expensive and locally available materials. Materials studies are to develop paint-on sealants to be applied on the small cement digester structures used in many developing countries to provide water- and gas-tight seals.

(Estimated funding requirements: $380,000. Portions of this study may be subcontracted to other countries with a cost-sharing potential.)

Charcoal Production from Biomass: Fast pyrolysis for production of gases is an important U.S. research area. This work can be complemented by extending the study of the basic pyrolysis processes at low temperatures, and by emphasizing chars production which has great applicability for cooking and heating purposes. The process should be studied to optimize the production of useful products such as charcoal, gas, and other chemicals from agricultural wastes and wood.

(Estimated funding requirements: $300,000.)

**Important**

Bioconversion of Residues: This area studies microorganisms and feedstocks typical of foreign countries, especially in the tropical belt, which may be useful to the United States in complementing the domestic research effort in converting lignocellulose to alcohols and other chemicals.

(Estimated funding requirements: $800,000.)

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | N/A | | |
| Applied Research | | | | | |
| Crucial | 545 | 225 | 145 | 115 | 90 |
| Important | 300 | 190 | 150 | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 845 | 415 | 295 | 115 | 90 |
| Exploratory Development | | | | | |
| Crucial | 330 | 130 | 90 | 90 | 40 |
| Important | 200 | 200 | 200 | 200 | — |
| Needed | — | — | — | — | — |
| Subtotal | 530 | 330 | 290 | 290 | 40 |
| TOTAL | 1,375 | 745 | 585 | 405 | 130 |

# SECTION 7.0

# CROSSCUT TECHNOLOGIES

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## 7.1 MATERIALS RESEARCH AND DEVELOPMENT

Solar materials research is aimed at reducing the elements of life-cycle cost for all solar energy systems to improve cost effectiveness. The life-cycle cost elements are capital costs, performance versus time, and useful working life. Basic materials research is aimed at understanding the fundamental properties of materials and the degradation mechanisms associated with decreased performance (e.g., optical, mechanical, and protective).

The data derived from basic research may allow a quantum leap in technology, provide a new class of less expensive or more effective materials for evaluation, and allow the development of accelerated lifetime tests. It is the nature of basic research that some exploratory activities may anticipate defined technologies by 10 or 20 years (e.g., photocatalysis).

Applied materials research is designed to strengthen the understanding of how specific materials perform and degrade in long-term exposure to the environment created by solar energy conversion systems. These efforts will help provide candidates for substitution that will improve cost and lifetime, and may improve performance.

Exploratory development is aimed at quantifying the cost benefit of making particular materials substitutions or incorporating new materials. Exploratory development provides the statistics to refine the estimates of performance and lifetime as a material moves from the well-defined laboratory environment and limited availability to large-scale production with system and time variability. The primary objective of all three activities is to provide characterized materials which offer significant improvements in initial system cost and reliability without major sacrifices in performance.

### Basic Research

Basic research is required to increase scientific knowledge of materials phenomena which relate the materials' properties to their function. Priorities have been assigned by viewing the relative importance of the research in a benefit framework which supports all of the solar conversion technologies.

#### Crucial

Areas crucial to basic research include:

- fundamental studies to improve the photodegradation resistance of polymeric materials and accurately predict lifetime;
- surface science to improve characterization of solid/solid, solid/liquid, and solid/gas interfaces (photocatalysis, reflector/absorber degradation, PV interfaces, corrosion in biochemical and solar thermal systems); and
- establishing the relationship between the microstructure/chemistry of thin films, the permeability of these films for protective coatings (encapsulants, mirror backing paint), and membranes.

**Important**

Research goals in this area should include:

- an improved understanding of the micromechanics of composite materials based on renewable resources; e.g., wood fibers;
- studies of the physics and chemistry of adhesion;
- establishing a relationship between microstructure/chemistry and optical properties and between microstructure/chemistry and photo/thermal stability of absorber and reflector films; and
- investigating the compatibility of inexpensive polymers as containers for fluids in heating and cooling and biochemical systems.

**Needed**

Ceramics and glass research is necessary in the areas of fracture toughness and structure property relationships and in improving the atomic understanding of crack growth and model-complicated chemical reactions in multiphase, multicomponent metallic systems.

**Applied Research**

Applied research is required to increase the scientific knowledge of specific materials and to solve identified near-term problems in the solar conversion technologies.

**Crucial**

Goals imperative to applied research are to:

- develop predictive models for optical degradation of structural polymer films and polymer encapsulating materials;
- develop alcohol/water separation membrane research;
- evaluate composite stresses, both mechanical and thermal, and solid-state device stacks;
- stabilize silver as a reflector material for optical applications;
- conduct research in real time and accelerated environmental degradation for all optical and structural materials systems; and
- conduct nondestructive evaluation of the degradation of metal, ceramic, and composite components in service.

**Important**

The study of fatigue in expensive structural materials is required.

**Needed**

Sucessful research development must include:

- studying the degradation of adhesive bonds and interfaces in structural and optical systems;
- studying the corrosion and compatibility of heat transfer media and fluid loop materials (all temperatures);
- determining the behavior of glass and ceramic fracture under solar system stresses; and
- developing an improved corrosion monitoring and prevention technology.

## Exploratory Development

This area includes activities to improve the performance and durability of materials used in solar energy conversion systems.

**Crucial**

Goals critical to exploratory development are development of:

- thin, high-solar transmittance glass, and handling and annealing techniques;
- an inexpensive, durable, high-performance solar concentrator based on composites or thin-film materials;
- high-performance, durable silver or silver-alloy reflectors on thin glasses and polymers;
- reliability and lifetime test methods for solar materials;
- inexpensive, reinforced polymer containers for low-temperature thermal collectors, solar ponds, and biomass processors; and
- wood, paper, and plastic composite structural material.

**Important**

Areas of significance include development of:

- alcohol/water separation processes;
- delamination-resistant composites and components; and
- corrosion control and monitoring systems to improve collector and heat transfer system life.

**Needed**

Exploratory development to reduce composite stresses in solar components and to develop failure models for stressed and cycled components is needed.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| Important | 500 | 500 | 500 | 500 | 500 |
| Needed | 500 | 500 | 500 | 500 | 500 |
| Subtotal | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| Applied Research | | | | | |
| Crucial | 3,000 | 5,000 | 6,000 | 6,000 | 5,000 |
| Important | 2,000 | 5,000 | 4,000 | 4,000 | 5,000 |
| Needed | 1,000 | 1,000 | 4,000 | 4,000 | 1,000 |
| Subtotal | 6,000 | 11,000 | 14,000 | 14,000 | 11,000 |
| Exploratory Development | | | | | |
| Crucial | 3,000 | 3,000 | 4,000 | 4,000 | 3,000 |
| Important | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| Needed | 1,000 | 1,000 | 2,000 | 2,000 | 1,000 |
| Subtotal | 6,000 | 6,000 | 8,000 | 8,000 | 6,000 |
| TOTAL | 15,000 | 20,000 | 25,000 | 25,000 | 20,000 |

**References**

Bergeron, K. D.; et al. 1980 (April). Line-Focus Solar Thermal Technology Development. SAND 80-0865.

Call, Patrick J. 1979 (January). National Program Plan for Absorber Surfaces R&D. SERI/TR-31-103. Golden, CO: Solar Energy Research Institute.

Masterson, Keith. 1979 (July). Solar Optical Materials Program Activity Committee. SERI/PR-31-137. Golden, CO: Solar Energy Research Institute.

Pohlman, Steven, Chairman, Containment Materials Coordinating Committee. 1980 (March). Containment Materials for Solar Thermal Energy Transport Systems: An Overview of Research and Development Needs. SERI/MR-334-247. Golden, CO: Solar Energy Research Institute.

PRC Energy Analysis Co. n.d. A Guide to the Solar Thermal Program Fiscal 1980. Washington, DC: U.S. Department of Energy.

Solar Glass Coordinating Committee. 1979 (January). Solar Glass Mirror Program—A Planning Report on Near-Term Mirror Development Activities. SERI/RR-31-145. Golden, CO: Solar Energy Research Institute.

U.S. Department of Energy, Assistant Secretary for Conservation and Solar Energy. 1980 (January). Solar Energy Program Summary Document. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1978 (April). Research Projects in the Physical Sciences. DOE/ER-0003(78). Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1979 (September). Materials Sciences Program Fiscal Year 1979. DOE/ER-0031. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1978 (May). Solar Heating and Cooling Research and Development Project Summaries. DOE/CS-0010. Washington, DC: U.S. Department of Energy.

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## 7.2 RESOURCE ASSESSMENT

The potential of solar energy conversion systems depends on available solar energy. Consequently, to identify attributes and shortcomings of technologies and systems requires an accurate knowledge of the available resources. In addition, the successful application, commercialization, and marketing of solar energy systems requires an accurate knowledge of the amount, temporal characteristics, spatial characteristics, and detailed properties of solar energy. This resource assessment is essential to the utilization and management of any energy source. For example, an accurate estimate of the oil and coal reserves is vital to their utilization and management.

The overall objective of resource assessment is to further the development, commercialization, and application of solar energy by providing an adequate data base(s) for characterizations, models (prediction and forecasting), and assessments of national solar energy. The federal program in solar energy resource assessment was initiated and authorized by the 1974 Solar Energy Act, P.L. 93-473, Sec. 5, "Resource Determination and Assessment." The specific objective, as defined by the 93rd Congress, was to complete regional and national appraisals of all solar energy resources, including data on insolation, wind, ocean thermal gradients, and potential for photosynthetic conversion.

Solar energy consists of insolation (sunshine); wind; ocean thermal gradients, waves, currents, and salinity gradients; and various biomass energy feedstocks. Unlike fossil and nuclear fuels, solar energy is extremely diverse and variable (U.S. DOE 1980). The variability is both temporal and spatial, caused largely by geophysical conditions; e.g., wind and insolation are largely controlled by weather conditions (clouds, dust, etc.), which vary seasonally and geographically (Geophysical Predictions 1978). Also, pollution and man-made structures can significantly alter solar resources. Biomass is extremely diverse consisting of residues from agriculture, livestock, and forests, plus woody, agricultural, and aquatic crops grown specifically for energy applications. Because of the wide spectrum of resources and their variability, this section will not present details of the required basic and applied research and exploratory development for assessment. Rather, it will present the common basic requirements of the different areas of solar energy.

The 1974 Solar Energy Act, P.L. 93-473, Sec. 5, "Resource Determination and Assessment," and the Department of Energy Climate Program Plan (1980) make similar statements regarding solar energy resource research to those presented in the following paragraphs.

### Basic Research

The basic research described below creates an adequate scientific knowledge and understanding of the various solar energy resources.

### Crucial

Research is required to establish the potential adverse impacts of man-made pollution and various natural events on the availability and characteristics of solar energy, such as reduced insolation due to jet contrails. Basic research must be performed to allow the forecasting, both near and long term, of the availability of the various solar energy resources.

**Important**

Basic research to gain a better understanding of the complex relationships between solar energy and basic geophysical processes; e.g., the influence of atmospheric conditions on available solar energy should be initiated.

## Applied Research

The applied research described below generates scientific knowledge that is directly applicable to solar energy assessment.

**Crucial**

Better techniques must be produced for predicting and establishing the actual amounts and characteristics of solar energy. These techniques consist of mathematical models, algorithms, and measurement devices (instrumentation).

**Important**

Improved procedures must be developed for periodically measuring the quality and quantity of all solar resources. These will lead to the information required to manage solar resources on a national basis.

## Exploratory Development

Exploratory development involves particular applications and products of solar energy assessment.

**Crucial**

A complete, accurate, and uniform geographical assessment of all solar energy resources in the United States must be developed periodically. This is required to compare and determine the specific role of each resource. Activities, arrangements, and procedures required for collecting, evaluating, and disseminating information relating to solar energy assessment must be completed.

**Important**

A system must be developed to allow near-time, almost real-time assessments of currently available solar energy resources. This is analogous to the systems that utilities now employ for conventional power generation assessments.

## Funding Requirement

1980 Dollars in Thousands

| | FY82 | FY83 | FY84 | FY85 | FY86 |
|---|---|---|---|---|---|
| **Basic Research** | | | | | |
| Crucial | 1,500 | 1,500 | 1,500 | 1,500 | 1,500 |
| Important | 500 | 500 | 500 | 500 | 500 |
| Needed | — | — | — | — | — |
| Subtotal | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| **Applied Research** | | | | | |
| Crucial | 2,000 | 2,000 | 2,000 | 1,500 | 1,500 |
| Important | 1,000 | 1,000 | 1,000 | 500 | 500 |
| Needed | — | — | — | — | — |
| Subtotal | 3,000 | 3,000 | 3,000 | 2,000 | 2,000 |
| **Exploratory Development** | | | | | |
| Crucial | 500 | 1,500 | 1,500 | 1,500 | 1,500 |
| Important | 500 | 500 | 500 | 500 | 500 |
| Needed | — | — | — | — | — |
| Subtotal | 1,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| TOTAL | 6,000 | 7,000 | 7,000 | 6,000 | 6,000 |

## Comments

The funding requirement given above are for all solar energy resources—insolation, wind, biomass, ocean, and hydro. The funding requirement is based, somewhat, on the actual previous budget for insolation resource assessment which was $3.8 million in FY80. (Insolation Resource Assessment 1978).

The Basic Energy Sciences (BES) Program has supported some research in basic geosciences (U.S. DOE 1980). This should be expanded to include the entire basic research program required for all the solar energy assessement.

## References

Department of Energy Climate Program Plan. 1980 (February 25) (Preliminary Draft). Volumes 1 and 2. Revision 5, Lawrence Livermore Lab. LLL-MISC-126.

Geophysical Predictions. 1978. Studies in Geophysics. Washington, DC: National Academy of Sciences.

Insolation Resource Assessment Project Action Plan, FY79 Through FY81. 1978 (March 17). U.S. Department of Energy, Environmental and Resource Assessment Branch.

U.S. Department of Energy, Assistant Secretary for Conservation and Solar Energy. 1980 (January). Solar Energy Program Summary Document FY80. Appendix B, "Solar Resources."

## 7.3 AGRICULTURE

Agriculture is a crosscut technology that primarily relates to applications of solar technologies within the agricultural sector, to biomass energy supply, and to energy conservation in agricultural production. Although many agricultural energy needs can be supplied by various solar energy conversion devices, biomass is an energy source that warrants principal research focus. Agriculture-related studies can be categorized as (1) allocation of costs and revenues for joint products; (2) supply management strategies for agricultural biomass; and (3) market development activities.

### JOINT PRODUCT RELATIONSHIPS IN AGRICULTURE

The food component of agricultural production has traditionally been the focus of agricultural supply, demand, and policy analysis. The value of jointly produced agricultural crop residues has been low relative to the fruit or grain output, and accounts for the research and productive efforts directed away from residue markets. Residue markets are poorly organized or nonexistent due to on-farm utilization of residues or lack of residue harvesting.

Prototype agricultural residue biomass and gasifiers have demonstrated potential for converting residues into useful energy forms at prices possibly competitive with traditional fuel sources. Widespread adoption will stimulate demand for residues as a feedstock and may distort traditional food/fuel price relationships. The objective of research in this area is to investigate how increases in residue values, relative to joint food crop values, will affect production techniques and food and residue supplies, markets, and prices. The potential for altering the traditional ratio of outputs, food versus residue output per unit effort, in response to changing price ratios could have a large impact on food production systems, consumer prices, and government agricultural programs.

#### Basic Research

The basic principles governing joint product (i.e., food/fuel) production have received extensive, theoretical consideration in economics literature. A number of mutually exclusive categories of joint product relations based on technical considerations can be identified. Categorizing crops with respect to production is a first step toward assessing the associated market and price effects.

#### Crucial

The most urgent need is to assess the existing literature on joint product relationships. It is important to establish the theoretical and technical considerations that distinguish joint product relationships and the theoretical impact of changing joint product output prices on producer behavior. The extent to which existing production and marketing patterns might be altered must be developed and the distinguishing parameters identified. A theoretical conceptualization will demonstrate the aspects of the problem requiring further investigation and indicate empirical relationships that must be estimated to quantify the joint products implications for supply and price analysis.

**Important**

Government agricultural support programs rely on production control measures to achieve output price and producer income objectives. Supply is controlled by the level of land set-aside required by producers for program compliance and associated program payments (price supports).

The amount of land set-aside needed in any year is determined by estimating producer response to program benefits and market prices. Producer response levels are based on historical conditions with residue portions contributing little to revenue and, therefore, not entering into set-aside evaluations. Should crop residues become more valuable, historic price response relationships may change and agricultural program planning could be affected adversely. The implications, important relationships, and parameters of joint product production should be defined for designing government support programs. In addition, the potential for price support payments for both the energy and food output should be considered in anticipation of government programs designed to encourage biomass energy production.

**Needed**

The theoretical work is expected to identify the technical and behavioral parameters that distinguish joint from single product relations. Differences in the technical conditions of production and in the degree of "jointness" of outputs are expected to lead to impact differences in relative price changes on product supplies. Categorizing biomass feedstocks according to a classification of jointness is needed to separate the various feedstocks. Categorizing feedstocks should facilitate supply analysis as groups of products with similar characteristics will be identified. Analyzing commodity groups instead of individual crops results in fewer cases considered and a time and effort savings.

**Applied Research**

Basic research efforts are expected to identify the important dimensions of supply analysis under joint production conditions. However, the impacts associated with the joint product case are generally not quantifiable from theoretical exercises. Empirical analysis is necesssary to establish the relative changes in supply, prices, etc., that occur with joint production and relative price changes. The objective of applied research is to quantify theoretical concepts and derive market implications.

**Crucial**

Biomass gasification and pyrolysis produces several feedstocks for the chemical industry; e.g., methanol and ethanol. The traditional feedstock source is the light fractions of oil in the petroleum refining process. The potential for substituting feedstocks from biomass sources depends on the joint product nature of petroleum refining. If feedstocks from biomass are produced in fixed proportions (with gasoline and other distillates), the reduction in oil use is expected to be small. However, if feedstock production in gasoline refining is joint but not fixed, then biomass-derived feedstocks have greater potential to substitute for petroleum. Establishing the technical nature of product jointness in petroleum refining is crucial in analyzing the market potential for biomass-derived feedstocks.

### Important

Current research needs require the modeling of production and marketing activities to determine the technical limits of substitution of biomass feedstocks for petroleum. Industry models of petroleum refining are available to analyze current production technology. These models need to be altered to examine the degree of technical substitution possible among refinery outputs, especially with respect to feedstock and liquid fuel products.

### Needed

Estimating the substitution potential of feedstock and liquid fuel products derived from biomass requires knowledge of current marketing arrangements among producers and buyers. Fixed-price and long-term contracts could adversely affect the potential for biomass feedstock penetration. A thorough study of the existing marketing and pricing mechanisms could indicate entry barriers to firms producing biomass feedstocks, rather than petroleum refining processes.

## REGIONAL BIOMASS/FOOD SUPPLY ANALYSIS

Basic research efforts have identified several technologies capable of converting agricultural residues into useful energy. Applications range from small-scale, on-farm converters to larger, commercial ventures to produce chemical feedstocks or electricity. Cost studies have identified the capital and operating costs associated with these conversion plants. However, actual plant costs and output prices depend on the availability and price of biomass residues. A more complete study of biomass conversion technologies must consider supply-inducing conditions for food and residues since the products are connected.

### Basic Research

The efforts to identify biomass conversion applications have been completed or are in progress. No additional program efforts are presently needed.

### Applied Research

The main objective of applied biomass/food supply research is to develop an agricultural production system model that characterizes supply-inducing factors for food crops and associated residues. Existing agricultural supply models are either commodity specific or national in scope, and generally ignore agriculture residue production. Forecasting residue supplies—an important element in estimating the location and production potential for residue conversions—requires a model that takes into account food and residue production relations. A regional approach is necessary to account for productivity differences, supply concentrations, transportation costs for biomass-derived fuels, and producer response to output prices and government programs.

### Crucial

The most crucial need is to incorporate biomass residue production relationships in food production models. Biomass residues can be supplied from several food crops; a biomass/

food supply model, therefore, must consider the production of several crops. National models are too aggregated to account for supply differences due to climatic and soil characteristics. Existing models may help identify the level of important parameters and/or develop a methodology for characterizing the production of food crops and associated biomass residues. A complete analysis, however, requires a renewed modeling effort to integrate food with biomass production relationships.

**Important**

Agricultural commodity programs are designed to regulate the supply of certain food crops by controlling the amount of land devoted to production. The historic emphasis of agricultural policy has been to balance food needs against farm income objectives. Program controls and incentives were adjusted to achieve the desired commodity supply and attendant producer price and income benefits.

Pending legislation (Agricultural, Forestry, and Rural Energy Act of 1979 - Title II of §.932) authorizes the Secretary of Agriculture to integrate energy policy objectives into existing food production programs. However, the nature of producer response to government program provisions is not only generally developed. The implementation of additional program benefits and requirements to accommodate energy feedstock production will require a clear understanding of producer response to production controls and incentives. Inevitable trade-offs among food and energy production objectives can be resolved only by thoroughly understanding the link between policy interest and actual producer response.

**Needed**

A thorough review of existing agricultural legislation and proposed energy production incentives is needed to identify possible conflicts. Understanding the operation of existing agricultural programs is tantamount to developing a consistent energy production policy for agricultural crops. Identifying energy production levels as objectives is not sufficient to ensure that the required infrastructure is developed. Efforts to encourage adoption of biomass conversion must be predicated on knowledge of existing supply relationships and the effects of government program intervention.

## MARKET DEVELOPMENT ACTIVITIES

Market development activities in agriculture fall into only two functional categories. Basic research results from other subprogram elements will be used, but the activities in this area presume a technology well enough developed to compete with conventional energy alternatives.

### Applied Research

Market development activities require market identification and characterization, an information base to facilitate technology acceptance, and identification of state and federal policies directly affecting purchase and production decisions.

**Crucial**

Market identification and characterization requires fundamental knowledge to actively participate in the development of new markets for biomass products. Market identification specifies the information necessary to narrow the focus of development activities for the maximum benefit. Market characterization includes price, output, cost, other financial and economic data, as well as matching energy systems and products to present needs.

**Important**

Agriculture and energy policies directly affect the production and consumption of biomass energy products. Once potential markets are identified and characterized, policy studies should be initiated to eliminate conflicts and barriers to acceptance of biomass products. Important agricultural policy studies include inventory management for sustained yields, assurance of long-term feedstock contracts, and development of a future market for agricultural energy products. Price regulations on conventional and biomass energy products directly affect market development activities.

**Needed**

Applied research needed for successful market development for agricultural biomass specifically pertains to developing an information base to facilitate acceptance. Prospective producers and consumers are deluged with conflicting information that make investment decisions difficult. The information base should be cross-referenced and should devote substantial resources to indexing, abstracting, and summarizing major areas of the literature.

**Exploratory Development**

Market development activities require exploratory development of marketing contracts to secure long-term biomass feedstock supplies, execution of contract trades for infrastructure development, and modeling and analysis of existing future markets to include biomass feedstocks.

**Crucial**

The principal deterrent to construction of biomass energy conversion equipment is the possibility that feedstock supplies may become scarce or so expensive that profitability is lost. An understanding of agricultural marketing contracts is required, and development of alternative arrangements is necessary for the successful development of biomass energy product markets. It is also crucial to conduct on-going technical and economic assessments of emerging technologies to ensure that market development activities do not promote systems becoming quickly outdated (e.g., ethanol vs. methanol).

**Important**

Once marketing relationships are understood and alternative contracts are devised, actual trading history is required to allow firms to understand how these contracts operate. Novel methods should not be disregarded and emphasis should be placed on reducing risks and uncertainties of inflation, interest rates, and conventional energy costs.

**Needed**

If a market develops for biomass products, long-term contracts will solve only one aspect of the feedstock supply problem. Liquidity of feedstock supplies is necessary to allow optimum economic efficiency of existing productive capacity. One means is the development of a futures market for biomass feedstocks. The consequences of such actions should be understood before a commitment is initiated.

## WIND ENERGY CONVERSION—MARKET DEVELOPMENT

The potential value of wind energy conversion systems (WECS) to the agricultural community is high, relative to many other dispersed applications, due to siting opportunities in rural areas, large markets, and rising costs of conventional energy supplies.

### Basic Research

Basic research activities in WECS agricultural market development focus on issues of cost, performance, and reliability. These issues become important for determining the economic feasiblility of WECS in specific agricultural applications.

**Crucial**

Performance and reliability issues are being addressed in the specific program elements of the U.S. DOE Wind Program. NASA-Lewis, Sandid, PNL, and Rocky Flats have developed programs which help quantify these parameters. Communication of results to the academic and applied research communities is crucial. However, the potential end user requires reliable wind regime data specific to his location to evaluate WECS performance and potential energy savings. Extrapolation of long-term wind data to locations from the meteorological stations is required. The short-term (e.g., 6 months) wind measurements at potential sites are expensive and time consuming. Methods of relating short-term wind measurements on location to long-term averages in wind regime measurements at distant meteorological stations are critical.

**Important**

The second level focuses on basic energy consumption data in specific agricultural markets. The USDA Energy and Agriculture Report (1974) helped to define these data gaps; however, further data are required on energy consumption as a function of farming practice (e.g., type of crops) and on farm size by state.

**Needed**

As the agricultural community shifts from energy intensive practices, the impacts on future farm energy consumption need to be addressed to present realistic appraisals for WECS applications in agriculture.

## Applied Research

Agricultural applications offer a unique and early market for WECS development. However, sales for agricultural applications are lagging due to the inability of individual farmers to evaluate the potential of WECS. The application of WECS on farms depends on information concerning present energy consumption (see Basic Research—Important/ Needed), energy use patterns, wind regime data, and the interface equipment specifications required for reliable and economical WECS power generation.

### Crucial

The development of a WECS/agricultural market depends on individual farmer's ability to comprehend and evaluate the specific parameters for economic WECS power generation. These information requirements need to be communicated to the agricultural community through outreach and extension service programs. Such information might include equipment specifications, alternative application schemes, and available federal, state, and local incentives.

Another crucial area is the examination and assessment of the potential impacts of §201 and §.210 of the PURPA regulations and the new tax credits (up to 40%) for WECS. PURPA requires utilities to interconnect with on-site generation equipment (e.g., WECS) and to purchase or buy back excess electricity generated by these sources. Combined with the favorable tax credit, many farmers owning vast acreage in high-wind regimes may become net exporters of electric energy.

### Important

The technology development and equipment interface requirement studies being conducted in the USDA wind program will satisfy some of the crucial needs of applied research. The results of the USDA activities must be addressed in view of present-day farming practices. Analyses of several WECS application interfaces to maximize their value and maintain their reliability are important. In conjunction with the USDA results, studies addressing end-user requirements in specific agricultural applications will provide operational and economic parameters to individual farmers.

### Needed

After initial sales and market development, the service and maintenance requirements for reliable WECS generation will necessitate formation of a service and maintenance infrastructure. The ability to use and rely on existing infrastructure arrangements established with other farm equipment needs to be explored in detail to successfully commercialize WECS.

## Exploratory Development

### Needed

Although technology information dissemination networks are well established in agriculture (particularly cooperative extension), it is necessary to understand the basic factors which may affect the adoption of energy-producing technologies in agriculture and to assess the proper roles of various institutions to deliver R&D findings to ultimate users.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 1,000 | 500 | 250 | 250 | 250 |
| Important | 1,500 | 1,000 | 500 | 500 | 500 |
| Needed | 500 | 250 | 250 | 250 | 250 |
| Subtotal | 3,000 | 1,750 | 1,000 | 1,000 | 1,000 |
| Applied Research | | | | | |
| Crucial | 2,000 | 2,000 | 1,500 | 1,000 | 500 |
| Important | 700 | 1,000 | 500 | 500 | 500 |
| Needed | 750 | 500 | 500 | 500 | 500 |
| Subtotal | 3,450 | 3,500 | 2,500 | 2,000 | 1,500 |
| Exploratory Development | | | | | |
| Crucial | 100 | 100 | 100 | 100 | 100 |
| Important | 250 | 200 | 200 | 200 | 200 |
| Needed | 200 | 150 | 150 | 150 | 150 |
| Subtotal | 550 | 450 | 450 | 450 | 450 |
| TOTAL | 7,000 | 5,700 | 3,950 | 3,450 | 2,950 |

## 7.4 TRANSPORTATION

The objective of this program element is to facilitate rapid development of energy-efficient transportation systems based on renewable fuels. Given the obvious importance of transportation in the total U.S. energy consumption and domination in terms of petroleum, the research and exploratory development tables identified should be assigned a high priority.

### Basic Research

Energy efficiency and use of renewable fuels are relatively new concerns in the United States. Substantial private resources recently have been devoted to these possibilities, and much of the need is engineering development. However, if long-term progress is to be achieved in the transportation sector, basic research focusing on materials needs, advanced combustion research, and storage is necessary.

#### Crucial

A crucial area is research aimed at improving basic understanding of the chemical, physical, and structural properties of various materials needed for energy-efficient and renewable-fueled vehicles. Examples of these materials include tires and lubricants designed for longer life and energy-efficient friction properties, and structural properties of materials for light-weight vehicles.

#### Important

Important research topics focus on the fundamental properties of combustion processes and how they can be made more efficient and cleaner. Research on alternative fuels, in terms of potential supply and conversion properties, is also important.

#### Needed

Basic research is needed in the area of improved storage materials and systems for electric and hybrid vehicles.

### Applied Research

Much of the activity in applied research would involve the same general considerations as those listed under basic research—particularly materials research—but would be directed toward the specific energy requirements of transportation.

#### Crucial

Applied physics, chemistry, and combustion research is needed for the future engineering development of high-efficiency, low-emission engines fueled by various liquid and gaseous fuels, such as diesel, ethanol, hydrogen, and methanol.

**Needed**

Large-scale adoption of energy-efficient technologies and vehicles powered by renewable fuels may effect major changes in the transportation sector, particularly in the automotive industry and fuel distribution channels. Applied research identifying these changes and their impacts on industrial structure is necessary to determine if various policy goals are achievable and desirable.

Other research areas are exploring the potential for on-site energy production from agricultural products, such as methane from anaerobic digestion and ethanol from grain stills. Success requires matching on-site fuel use to production, i.e., converting existing vehicles to operate on locally produced fuels. Research is needed to identify the technical potential for vehicular conversion and assess its costs.

**Exploratory Development**

A variety of renewable fuels, energy-efficient engines, and vehicle structures is technically feasible, but possible innovation in various transportation applications must be examined. However, most of these needs are appropriately labeled as technology or engineering development and therefore are not included in this report.

**Crucial**

A comprehensive, interdisciplinary study must be conducted to identify promising areas of research in transportation applications and provide a listing of basic and applied research needs. This assessment should be accompanied by a careful analysis of broad societal options over the long term. Examples include the feasibility and impacts of intermodal shifts, population distribution, alternative fuels, and conversion possibilities.

**Funding Requirement**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 1,500 | 1,500 | 1,500 | 1,500 | 1,500 |
| Important | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| Needed | 500 | 500 | 500 | 500 | 500 |
| Subtotal | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| Applied Research | | | | | |
| Crucial | 1,500 | 1,500 | 1,500 | 1,500 | 1,500 |
| Important | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| Needed | — | — | — | — | — |
| Subtotal | 2,500 | 2,500 | 2,500 | 2,500 | 2,500 |
| Exploratory Development | | | | | |
| Crucial | 1,000 | 1,000 | 1,000 | 750 | 500 |
| Important | — | — | — | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 1,000 | 1,000 | 1,000 | 750 | 500 |
| TOTAL | 6,500 | 6,500 | 6,500 | 6,250 | 6,000 |

# SECTION 8.0

# FINANCIAL FORECAST SUMMARY

SERI

## INTRODUCTION

This section summarizes the financial data for the Solar Energy Program previously presented in each program element. The Program's financial data are supported by subprogram financial summaries, including one for the crosscutting technologies. These immediately follow the financial forecast summary for the Program.

### SOLAR ENERGY PROGRAM

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 19,000 | 20,085 | 20,893 | 19,480 | 20,760 |
| Important | 13,480 | 13,965 | 13,458 | 12,474 | 12,155 |
| Needed | 5,450 | 4,970 | 4,642 | 4,070 | 3,890 |
| Subtotal | 37,930 | 39,020 | 38,993 | 36,024 | 36,805 |
| Applied Research | | | | | |
| Crucial | 69,595 | 80,640 | 75,170 | 69,596 | 67,447 |
| Important | 24,560 | 26,260 | 24,315 | 22,000 | 21,235 |
| Needed | 5,575 | 5,220 | 7,847 | 7,730 | 4,625 |
| Subtotal | 99,730 | 112,120 | 107,332 | 99,326 | 93,307 |
| Exploratory Development | | | | | |
| Crucial | 45,730 | 52,280 | 62,875 | 64,367 | 57,800 |
| Important | 16,000 | 17,180 | 16,497 | 15,054 | 12,865 |
| Needed | 5,600 | 5,650 | 6,260 | 6,650 | 4,900 |
| Subtotal | 67,330 | 75,110 | 85,632 | 86,071 | 75,565 |
| TOTAL | 204,990 | 226,250 | 231,957 | 221,421 | 205,677 |

**Solar Building Systems**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 3,900 | 4,300 | 4,500 | 3,200 | 3,500 |
| Important | 3,180 | 3,130 | 2,500 | 2,050 | 1,820 |
| Needed | 1,700 | 1,450 | 1,100 | 1,000 | 800 |
| Subtotal | 8,780 | 8,880 | 8,100 | 6,250 | 6,120 |
| Applied Research | | | | | |
| Crucial | 39,450 | 44,450 | 39,500 | 34,750 | 32,300 |
| Important | 3,160 | 3,460 | 3,060 | 2,260 | 2,210 |
| Needed | 1,250 | 1,200 | 1,200 | 1,100 | 1,100 |
| Subtotal | 43,860 | 49,110 | 43,760 | 38,110 | 35,610 |
| Exploratory Development | | | | | |
| Crucial | 18,000 | 22,400 | 31,450 | 32,750 | 30,550 |
| Important | 3,550 | 4,250 | 4,250 | 4,050 | 2,550 |
| Needed | 1,900 | 1,900 | 1,900 | 1,900 | 1,800 |
| Subtotal | 23,450 | 28,550 | 37,600 | 38,700 | 34,900 |
| TOTAL | 76,090 | 86,540 | 89,460 | 83,060 | 76,630 |

**Solar Industrial Applications**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 8,150 | 9,315 | 10,046 | 9,850 | 10,735 |
| Important | 4,200 | 5,020 | 5,372 | 4,960 | 5,385 |
| Needed | 1,100 | 1,110 | 1,121 | 635 | 645 |
| Subtotal | 13,450 | 15,445 | 16,539 | 15,445 | 16,765 |
| Applied Research | | | | | |
| Crucial | 12,550 | 16,500 | 15,055 | 14,711 | 15,982 |
| Important | 6,650 | 6,965 | 6,811 | 6,190 | 6,115 |
| Needed | 1,700 | 1,720 | 1,347 | 1,430 | 1,325 |
| Subtotal | 20,900 | 25,185 | 23,213 | 22,331 | 23,422 |
| Exploratory Development | | | | | |
| Crucial | 8,500 | 7,750 | 6,525 | 6,827 | 5,660 |
| Important | 8,150 | 8,465 | 7,811 | 7,190 | 6,615 |
| Needed | 2,500 | 2,600 | 2,210 | 2,350 | 1,950 |
| Subtotal | 19,150 | 18,815 | 16,546 | 16,367 | 14,225 |
| TOTAL | 53,500 | 59,445 | 56,298 | 54,143 | 54,412 |

**Solar Power Systems**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | — | — | — | — | — |
| Important | 1,450 | 1,600 | 1,800 | 1,600 | 1,000 |
| Needed | 1,050 | 1,050 | 1,050 | 1,050 | 1,050 |
| Subtotal | 2,500 | 2,650 | 2,850 | 2,650 | 2,050 |
| Applied Research | | | | | |
| Crucial | 400 | 400 | 450 | 500 | 500 |
| Important | 8,050 | 5,900 | 6,000 | 5,700 | 5,000 |
| Needed | 375 | 300 | 300 | 200 | 200 |
| Subtotal | 8,825 | 6,600 | 6,750 | 6,400 | 5,700 |
| Exploratory Development | | | | | |
| Crucial | 13,300 | 15,300 | 17,000 | 17,000 | 15,000 |
| Important | 700 | 850 | 750 | 50 | 50 |
| Needed | — | — | — | 250 | — |
| Subtotal | 14,000 | 16,150 | 17,750 | 17,300 | 15,050 |
| TOTAL | 25,325 | 25,400 | 27,350 | 26,350 | 22,800 |

**Alcohol Fuels**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 950 | 970 | 1,097 | 1,180 | 1,275 |
| Important | 1,150 | 1,215 | 1,286 | 1,364 | 1,450 |
| Needed | 100 | 110 | 121 | 135 | 145 |
| Subtotal | 2,200 | 2,295 | 2,504 | 2,679 | 2,870 |
| Applied Research | | | | | |
| Crucial | 8,150 | 8,565 | 9,020 | 9,520 | 10,075 |
| Important | 1,700 | 1,745 | 1,794 | 1,850 | 1,910 |
| Needed | 500 | 500 | 500 | 500 | 500 |
| Subtotal | 10,350 | 10,810 | 11,314 | 11,870 | 12,485 |
| Exploratory Development | | | | | |
| Crucial | 1,000 | 1,100 | 1,210 | 1,350 | 1,450 |
| Important | 650 | 715 | 786 | 864 | 950 |
| Needed | — | — | — | — | — |
| Subtotal | 1,650 | 1,815 | 1,996 | 2,214 | 2,400 |
| TOTAL | 14,200 | 14,920 | 15,814 | 16,763 | 17,755 |

**Solar International**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | N/A | | |
| Applied Research | | | | | |
| Crucial | 545 | 225 | 145 | 115 | 90 |
| Important | 300 | 190 | 150 | — | — |
| Needed | — | — | — | — | — |
| Subtotal | 845 | 415 | 295 | 115 | 90 |
| Exploratory Development | | | | | |
| Crucial | 330 | 130 | 90 | 90 | 40 |
| Important | 200 | 200 | 200 | 200 | — |
| Needed | — | — | — | — | — |
| Subtotal | 530 | 330 | 290 | 290 | 40 |
| TOTAL | 1,375 | 745 | 585 | 405 | 130 |

**Crosscutting Technologies**

| | 1980 Dollars in Thousands | | | | |
|---|---|---|---|---|---|
| | FY82 | FY83 | FY84 | FY85 | FY86 |
| Basic Research | | | | | |
| Crucial | 6,000 | 5,500 | 5,250 | 5,250 | 5,250 |
| Important | 3,500 | 3,000 | 2,500 | 2,500 | 2,500 |
| Needed | 1,500 | 1,250 | 1,250 | 1,250 | 1,250 |
| Subtotal | 11,000 | 9,750 | 9,000 | 9,000 | 9,000 |
| Applied Research | | | | | |
| Crucial | 8,500 | 10,500 | 11,000 | 10,000 | 8,500 |
| Important | 4,700 | 8,000 | 6,500 | 6,000 | 6,000 |
| Needed | 1,750 | 1,500 | 4,500 | 4,500 | 1,500 |
| Subtotal | 14,950 | 20,000 | 22,000 | 20,500 | 16,000 |
| Exploratory Development | | | | | |
| Crucial | 4,600 | 5,600 | 6,600 | 6,350 | 5,100 |
| Important | 2,750 | 2,700 | 2,700 | 2,700 | 2,700 |
| Needed | 1,200 | 1,150 | 2,150 | 2,150 | 1,150 |
| Subtotal | 8,550 | 9,450 | 11,450 | 11,200 | 8,950 |
| TOTAL | 34,500 | 39,200 | 42,450 | 40,700 | 33,950 |