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Basic Research Needs and Priorities in Solar Energy

Volume I

Executive Summary

MASTER

T.S. Jayadev
D. Roessner, Editors

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Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

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BASIC RESEARCH NEEDS AND PRIORITIES IN SOLAR ENERGY

VOLUME I
EXECUTIVE SUMMARY

TECHNOLOGY CROSSCUTS FOR DOE

T. S. JAYADEV
D. ROESSNER, EDITORS

JANUARY 1980

PREPARED UNDER TASK NO. 3142.15

Solar Energy Research Institute

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Golden, Colorado 80401

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FOREWORD

This executive summary condenses the findings of a SERI technical report which identifies basic research needs that are important to the development of solar energy. The report was prepared in response to a request from the Associate Director for Basic Energy Sciences, Office of Energy Research, U.S. Department of Energy. The full technical report is Volume II of SERI/TR-351-358.

The project was led by T. S. Jayadev of the Research Division and David Roessner of the Analysis Division. Michael Genest, a summer intern from the University of California, Berkeley, served as Research Associate on the project and made a major contribution to this report. Members of the SERI task force assembled to carry out the project were:

T. S. Jayadev (Chairman, Natural Sciences) - Solid State Physics
- Engineering and Mathematics
- Advanced Energy Projects

David Benson (Vice Chairman) - Metallurgy and Ceramics
John S. Connolly and Thomas A. Milne - Chemical Sciences
Michael Seibert and Ruxton Villet - Biological Energy Research
Alvin W. Czanderna - Materials Chemistry
J. David Roessner (Chairman, Social Sciences) and Bert Mason - Behavioral and Social Sciences

In addition, Arthur Nozik (Chemical Sciences) and Joel Cohen (Mathematics) assisted in the preparation of this report.

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SOLAR ENERGY RESEARCH INSTITUTE

K. J. Touryan
Assistant Director for Research

PREFACE

OVERVIEW OF SOLAR ENERGY TECHNOLOGY

By: J. Charles Grosskreutz

Solar energy conversion can be categorized by the processes of the physical interaction of solar radiation with matter (SERI 1979, MR-12-207). Figure P-1 is a schematic representation of the two major absorption processes: the production of heat and quantum interactions. Both processes, by means of suitable conversion mechanisms, can lead to useful energy products. These two general conversion processes or paths are referred to as Thermoconversion and Photoconversion. Given today's knowledge, they are the only two paths currently available. The most common conversion technologies that use the two primary interactions are flat-plate collectors which convert the heat produced by thermoconversion to hot water or air, and photovoltaic cells which convert the electron-hole pairs created in semiconductors by photoconversion to an electric current.

A more detailed view of the multiple conversion pathway with thermoconversion and photoconversion is shown in Figs. P-2 and P-3. These figures are arranged so that from bottom to top one moves from already or nearly commercialized technologies to those which are not yet out of the basic research stage. Similarly, the photoconversion paths may be placed above the thermoconversion paths so that the same vertical axis takes one from relatively simple mechanical and structural systems in thermoconversion to highly sophisticated, solid state biological and chemical systems in photoconversion.

Another way of viewing the phenomenological framework shown in Figs. P-2 and P-3 is to use the horizontal axis to designate how far a particular conversion mechanism has progressed along the RD&D sequence. The wavy shaded line denotes that (fuzzy) boundary between what is already known, understood, or developed (the area to the left); and the region where research is still required to advance the technology (the area to the right). Clearly, lowhead hydro and wind turbine technology are in various stages of engineering development, while photobiological and photochemical conversion still require research in the mechanisms of primary product formation. Photovoltaic research is now concentrating on conversion mechanisms and device technology, with single-crystal silicon much further advanced than other materials such as gallium arsenide or amorphous silicon.

Any new conversion technology must fit into this overall scheme, either deriving from primary quantum processes or from the heat produced in some absorber. Note, too, that storage of the energy produced along any of these paths can occur at any point along the horizontal axis; e.g., storage of the final electricity product in batteries, or of the primary excited photochemical states in a suitably stable chemical compound.

Furthermore, the horizontal axis is a continuum in mission-oriented research. Domains of fundamental research occur near the left side. These evolve into mission-oriented research as one proceeds to the right and begins engineering research and development, market and policy analysis, and the commercialization activities required for the marketplace to accept the technology. The position of the wavy shaded line expresses qualitatively the kind of research still required and distinguishes the near-term technologies from those far removed from application.

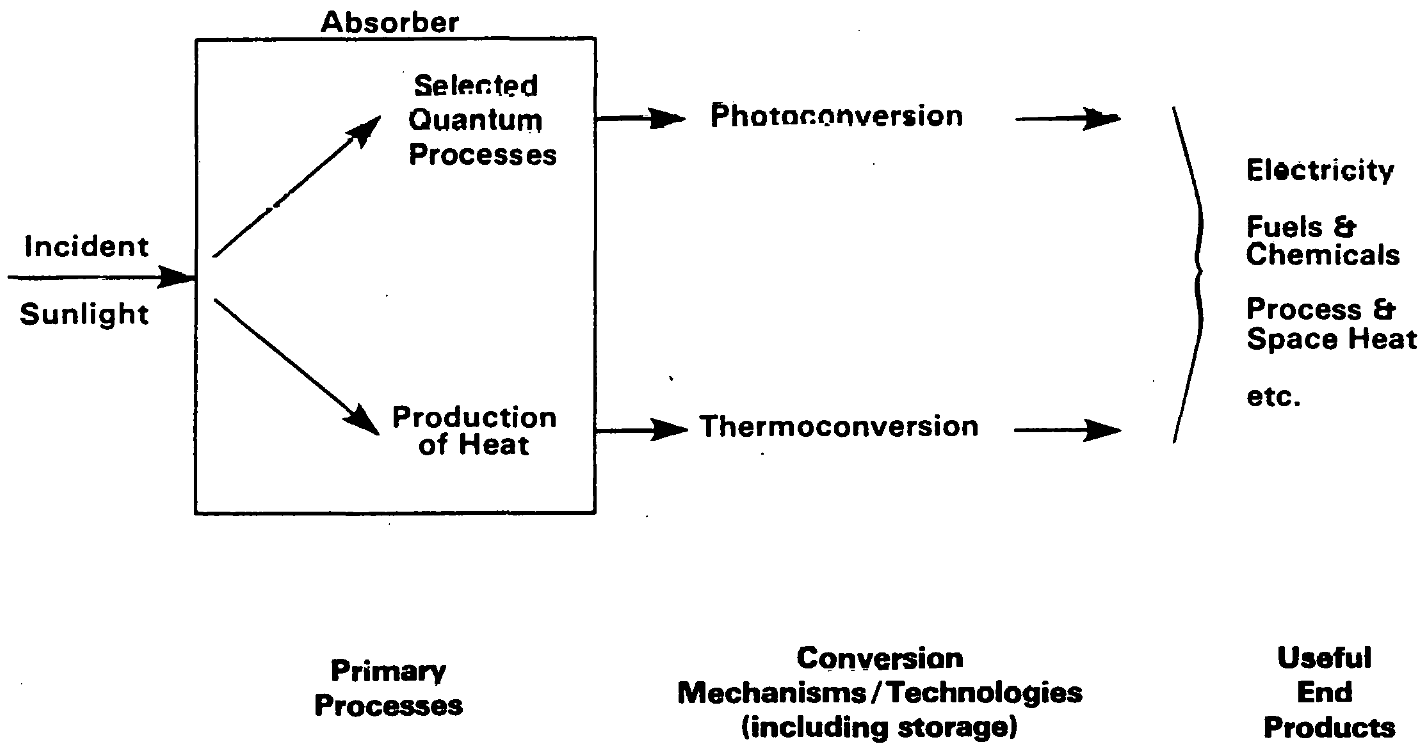

Figure P-1. Solar Radiation Processes and Conversion Paths

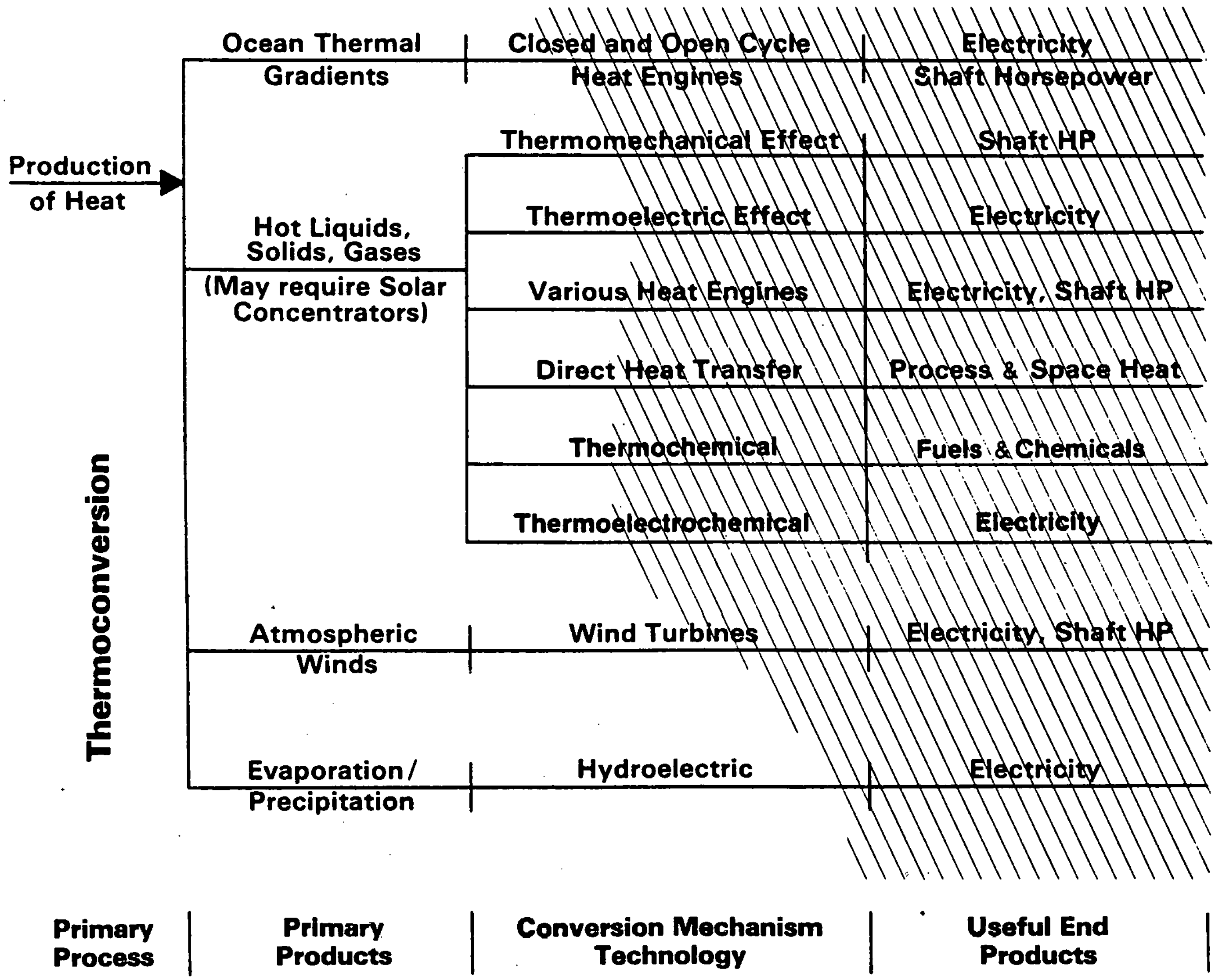

Figure P-2. Detailed Framework for Solar Thermoconversion Paths

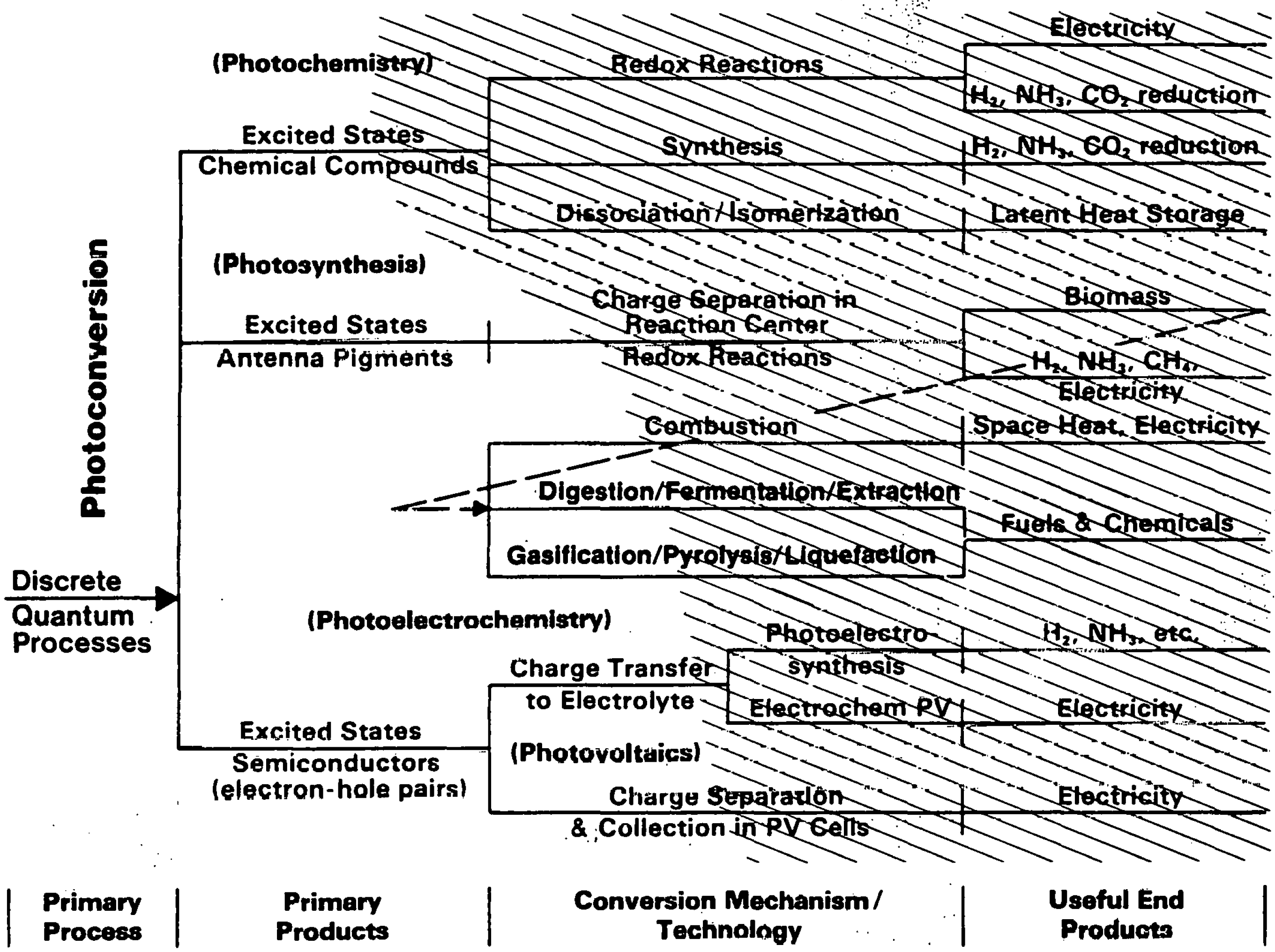

Figure P-3. Detailed Framework for Solar Photoconversion Paths

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1.0

INTRODUCTION

1.1 BACKGROUND

Energy supply and use issues are likely to command the attention of government policy makers from now until well into the next century. Tax revenues will continue to be spent to influence consumer energy choices and to develop and accelerate the commercialization of new energy technologies. Tax revenues will also continue to support the fundamental research needed to ensure a broad range of future energy options. How these research monies should be allocated among the myriad promising avenues is a continuing concern of energy policy makers. This report seeks to address that concern by providing the U. S. Department of Energy (DOE) with the results of an effort to identify the basic research needs and priorities in solar energy.

Research in solar energy must develop knowledge about how both the physical and social systems function. Achieving the nation's current solar energy goal, to produce 20% of the total energy consumed in the year 2000 through solar energy conversion, will be a challenge for both physical and social scientists engaged in solar energy research.

Current solar energy conversion technologies are probably not adequate to achieve the 20% goal. The solar energy conversion systems of the twenty-first century will be very different from today's systems. In this report we have tried to identify areas of research that will lead to new concepts for the year 2000 and beyond, in addition to those areas of research which must be pursued to develop nearer-term technologies. The products of solar energy are heat, electricity, chemicals, and fuels. Various physical phenomena can be exploited in order to convert solar radiation to each of these end products.* Conversion to heat is relatively straightforward and current programs, especially those conducted by DOE's Office of Energy Technology (ET), cover this area. But in the areas of conversion to the other end products, research is generally in the embryonic stage. Conversion of solar energy to electricity—either directly or via thermal processes—is still an emerging field where new concepts based on physical processes in solids, liquids, and gases seem certain to emerge in the near future. Research needs in these areas are described in the sections on Materials Sciences, Engineering, and Advanced Energy Research Projects. Conversion of solar radiation to fuels and chemicals, and to electricity via chemical and biological processes, is also a very promising and exciting area of research. Research needs in these areas are described in the sections on Chemical and Biological Sciences.

With the exception of conversion of solar energy to heat and biomass conversion, solar technologies will not mature for ten to twenty years or more. To reach maturity, these technologies will require research support in basic and applied sciences. This support must come from programs that focus on the special needs of solar energy as well as from the current programs which are organized according to scientific disciplines.

Public action will be taken over the next several decades to increase the number of available solar energy supply and use options; improve the cost, performance, and reliability of developing solar technologies; provide incentives to increase the market for

*See the Preface to this report, "An Overview of Solar Energy," by J. C. Grosskreutz.

solar technologies; and remove institutional and legal barriers that inhibit solar energy applications. If these actions are to be effective while also minimizing economic, social, and environmental costs, better understanding is needed of how consumer and industrial markets for energy supply technologies operate, what consequences are likely to result from large-scale use of solar technologies, and how government policies affect energy choices and private investment in the development of new energy technology. Such understanding must come from research in the Behavioral and Social Sciences.

Our society is built on the belief that knowledge about ourselves, our social system, and our physical environment will help us solve the problems we face. Energy issues now seem almost intractable in their complexity and show little promise of becoming simpler as the years pass. Immediate and near-term solar energy policy decisions hopefully will be illuminated by current, state-of-the-art knowledge. If future decisions are to be still better informed, government must invest now in basic research that can bear fruit in usable knowledge and analytical tools ten, twenty, thirty, or more years hence. The Behavioral and Social Sciences section of this report suggests areas of basic inquiry that we believe have the greatest likelihood of contributing to the appropriate development of solar energy within that time frame.

This assessment of basic research needs in the field of solar energy was undertaken at the request of DOE's Office of Basic Energy Sciences (BES). Specifically, BES requested that SERI identify the "lines of research (that) should be covered," provide guidance in assessing the relative importance of those lines of research, identify research areas "deserving very special emphasis," and identify the "principal issues concerning basic research" related to solar energy. Choice of the methods to be used in preparing the assessment was left to SERI's discretion with the understanding that it should represent the views of the broad scientific community and should not be limited to the opinions of SERI scientists alone. BES was hopeful that the finished document would be useful in "comparing priorities across divisional lines within BES."

1.2 METHOD

A committee composed of ten SERI scientists representing the major scientific disciplines important to solar energy was formed following the BES request. The first decision the committee faced was how to develop a representative description of research needs in solar energy. Wallace S. Sayre notes that scientists traditionally have been represented by outspoken, self-appointed, individual spokespersons; by small elite groups, some self-nominated, some the designees of government officials; by various scientific associations with broad scientific constituencies; or by specialized associations of scientists (Gilpin and Wright 1964). Thus, there is no existing group that can claim to represent "scientific opinion," nor is there an established, clearly defined group of scientists engaged in solar energy research.

Various methods for sampling the opinions of working scientists were considered, but many were deemed impractical, inefficient, or beyond the resources available to SERI. The method finally adopted rested on the knowledge that SERI scientists were in excellent positions to know the scope of solar energy research and identify key researchers in their fields. Each scientist on the committee sought the opinions of leading scientists in his or her field engaged in or knowledgeable of solar-related research. Initially, more than 120 scientists were interviewed by telephone to obtain their views on needed research topics. From these interviews, a preliminary draft listing these research topics by discipline was prepared and mailed to most of the scientists interviewed. Each was asked to review the draft and suggest changes in the list of research needs identified as well as to assign priorities within his or her field of expertise. This final version incorporates the responses to the first draft.

The committee scientists relied heavily on the opinions of scientists polled but occasionally deleted, augmented, or combined the specific recommendations of individuals polled in order to resolve contradictions and make comparisons more uniform. In addition, committee members weighted their own recommendations and opinions at least as heavily as those of the scientists they polled. The result is an amalgam of national scientific opinion representing the viewpoints of key researchers in relevant disciplines and of SERI research staff opinions.

The researchers queried are not fully representative of the full spectrum of solar energy scientists. Undoubtedly, many important and knowledgeable solar energy scientists were omitted. This was inevitable, given the time and resource constraints on the overall effort. Nevertheless, a broad range of scientists working at each major type of research institution contributed their opinions on research needs and priorities in solar energy. The report does not represent a national consensus or even a consensus among the groups surveyed, but we believe the result is a close approximation to "the scientific community's" views on research needs in solar energy.

1.3 THE PROBLEM OF SETTING PRIORITIES

Perhaps the most difficult and controversial aspect of this effort was the setting of priorities. While there is abundant literature on the question of policy choice in resource allocations to science, it generally approaches the question from a broad national perspective. For example, it addresses the problems of choice among broad areas of federally funded research such as medicine and space but seldom touches on the issues inherent in choices among narrow fields of research such as photochemistry and photobiology.

Alvin Weinberg provides some insight into this more specific type of scientific choice (Weinberg 1963, 1964). Weinberg proposes three sets of criteria for scientific choice—"scientific merit," "technological merit," and "social merit." "Social merit" is a broad concept having to do with considerations of national prestige, health, welfare, and military power. "Technological merit" refers to the balance between research costs and probable benefits attributable to a given line of research. ["Technological merit" is closely related to C. F. Carter's economic criterion (Carter 1963). Carter suggests that scientific effort be distributed in such a way as to maximize the flow of wealth to society.] "Scientific merit," the "internal criterion," depends upon the maturity of a field or technique for exploitation and the caliber of the practitioners who will be engaged in the research. While Weinberg did not propose these concepts as criteria for the more detailed level of scientific choice that this report addresses, "technogical merit" and "scientific merit" are concepts that can be useful in assigning priorities to research topics within broad fields such as solar energy.

In applying the criterion of "technological merit" to specific research projects, four parameters must be estimated: the probability that a project will result in a viable new technology, the likely benefit to society attributable to that technology, the time required to complete the research, and the likely cost of the research. Clearly, these parameters are extremely difficult to estimate accurately. How many scientists would be willing to assign a precise probability to the chances for success of a specific project? In the likely event that different scientists assigned widely different probabilities to the same project, who would choose the "correct" one? If estimates are pooled or averaged, would each be weighted equally or would some be given more credence than others? Efforts by committees of the National Academy of Sciences to apply this kind of thinking to setting research priorities in several fields of science have not been successful (Reagan 1969, pp. 270-302).

Nevertheless, consideration of these four parameters undoubtedly plays a part in scientific choice by public policy makers. No attempt was made, however, to formally incorporate a consideration of these parameters into the priority setting process in preparing this report. A methodology for doing so has not yet been developed.* It is likely, however, that many of the respondents considered such questions informally in making their recommendations.

Undoubtedly, the criterion of "scientific merit" was also considered by the respondents. Scientists are more aware than any other group of the readiness of a field for exploitation and of the caliber of practitioners available for doing the research. Again, no attempt was made to formally consider "scientific merit" in preparing this report for reasons similar to those just presented. Based on the priority rankings and substantive recommendations received from respondents, the committee scientists were asked to assign to each research topic one of three priorities. The levels of priority were defined as follows.

> Crucial: work that is essential if progress is to be made in an important area of solar energy; without research on this topic we have 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 area of solar energy.
>
> Needed: work that has a fair to good chance of helping to further the development of an important area of solar energy.

The committee chose these definitions over a simple "high," "medium," and "low" ranking system in an attempt to suggest the criteria of "technological merit" and "scientific merit." While these definitions partially capture the elements of these criteria, with the exceptions of research costs and caliber of practitioners available (estimates of these parameters were thought to be more appropriately left to BES decision makers and national laboratory administrators), they clearly are more suggestive than definitive. In practice, committee scientists found that the distinctions between the categories were blurred and, in assigning research topics to one or the other of these categories, they often relied heavily on personal judgments.

Since each committee scientist was responsible for a specific discipline, it is not possible to use the priorities as a basis for comparing research priorities across different disciplines. What is crucial to thermochemical conversion may be no more vital to the nation than what is important to photochemical conversion, or vice versa. BES clearly needs to make these kinds of comparisons, but this report cannot serve as the basis for doing so. Such comparisons are particularly difficult to make among fields in basic research. Federal agencies, of necessity, have been making such comparisons for many years. John G.

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*Some interesting work along these lines has been done by S. James Press and Alvin J. Harman of Rand. See Press and Harman; Methodology for Subjective Assessment of Technological Advancement. Rand; Santa Monica, CA: April 1975; R-1375.

Wirt et al. have described the various techniques these agencies have used (Wirt et al. 1974). While they do not attempt to evaluate these techniques, their description may prove helpful to BES in its efforts to design a method for making these difficult comparisons.

1.4 THE FORMAT OF THE REPORT

Each major section covers one scientific field, corresponding to the organizational structure of BES. With the exception of the section on Behavioral and Social Sciences (which is arranged according to generic areas of research needs), the sections are composed of subsections, each of which covers one scientific discipline. Each subsection was written by a committee scientist specializing in the discipline discussed. At the end of each subsection, there is a table of research needs within that discipline, arranged by priority classification. Priorities, always underlined, also appear in the text.

This format was chosen to facilitate quick access to the relevant parts of the text for readers interested only in particular disciplines.

SECTION 2.0

CHEMICAL SCIENCES

2.1 THERMAL CONVERSION OF BIOMASS

The crucial needs in thermal conversion of biomass are (1) for improved mechanistic and kinetic characterization of pyrolysis, gasification, and liquefaction, including the effect of catalysts; and (2) for better chemical and physical characterization of biomass and for exploratory electrochemical research.

Table 2-1. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: THERMAL CONVERSION OF BIOMASS

	Research	Priority
1.	Fundamental studies of slow and fast pyrolysis.	Crucial
2.	Thermodynamic, thermophysical, and optical property information of biomass and chars.	Crucial
3.	Development of catalysts for gasification and liquefaction.	Crucial
4.	Research on the fundamental reaction chemistry in liquefaction in aqueous and nonaqueous media.	Crucial
5.	Research in the area of electrochemical processing of biomass.	Crucial
6.	New formulations of organic reaction mechanisms under extreme thermal or photo fluxes.	Important
7.	Novel methods of temperature and composition measurement in heterogeneous systems.	Important
8.	Kinetic studies of secondary cracking of primary pyrolysis products.	Important
9.	Basic engineering studies of prototype reactors.	Important
10.	Demonstration of novel thermal processing methods (e.g., molten salts, microwave).	Important
11.	Characterization of environmentally hazardous conversion by-products.	Needed

2.2 THERMOCHEMICAL AND THERMOELECTROCHEMICAL CONVERSION OF SOLAR ENERGY

The crucial research needs in both thermochemical and thermoelectrochemical conversion of solar energy relate to the laboratory demonstration of the feasibility of novel cycles to produce chemicals, fuels, or electricity.

A detailed discussion of electrochemical research areas is contained in a report prepared for NSF entitled "Energy Workshop on Electrochemistry. A Report on Discussion of Energy-Related Basic Research in Electrochemistry" (Osteryoung et al. 1974).

Each of the subject areas just discussed is included in a forthcoming NAS report to NSF entitled "High Temperature Science: Future Needs and Anticipated Developments," which should be completed in 1979. Another report, being prepared for DOE by the NAS Committee on Chemical Science, will address aspects of basic research in the chemical sciences, including specifically solar energy, biomass energy, electrochemistry, and high-temperature chemistry.

Table 2-2. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: THERMOCHEMICAL AND THERMOELECTROCHEMICAL CONVERSION OF SOLAR ENERGY

	Research	Priority
1.	Demonstration of the feasibility of cyclic, dissociative, or N-fixing schemes.	Crucial
2.	Demonstration of thermally regenerable EMF cell cycles.	Crucial
3.	Study of modified electrodes, electrocatalysis.	Crucial
4.	Acquisition and critical evaluation of thermodynamic data.	Important
5.	Basic studies in reversible chemical systems for heat transport and storage.	Important
6.	Research to discover new solar-driven processes in metallurgy and biomass gasification.	Important
7.	Search for new solid electrolyte anion, cation, and gas conductors.	Important
8.	Microscopic description of ionic and electronic processes at solid/electrolyte interfaces.	Important
9.	Studies of novel high-temperature dissociated gas separation techniques.	Needed
10.	Studies of solar-assisted gasification of coal.	Needed
11.	Research on the use of ZrO_2 in high-temperature electrolysis of steam, CO_2.	Needed

2.3 PHOTOCHEMICAL CONVERSION AND STORAGE

Significant scientific advances in basic research are difficult, if not impossible, to predict. There is no way of deciding a priori when, or in what way, basic scientific exploration will "pay off." If such things could be forecast with any accuracy at all, there would be little point in doing the research (Thomas 1978). The specific opportunities listed in the table outline the kinds of research that are required in order for photochemical conversion to emerge as a self-sufficient technology. This research will provide a significant part of the knowledge required to develop new approaches to conversion and storage of solar energy.

Table 2-3. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: PHOTOCHEMICAL CONVERSION AND STORAGE

Research	Priority
1. Photosensitization:	
Define photophysical and photochemical parameters required for efficient capture and primary conversion of solar quanta.	Crucial
2. Redox Catalysis:	
Synthesis and characterization of molecules capable of serving as stable intermediates in sequential electron-transfer events.	Crucial/Important
3. Coupled Systems:	
Specific matching of 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 reduction of N_2 or CO_2.	Crucial
4. Unimolecular Storage:	
Mechanisms of direct and sensitized photoisomerization reactions and development of specific catalysts for the reverse processes.	Important
5. Theoretical Studies:	
Accurate, quantitative predictions of molecule properties.	Important
6. Instrumentation:	
Application of new techniques and development of new instrumentation.	Crucial/Important/Needed

2.4 PHOTOELECTROCHEMICAL ENERGY CONVERSION

Photoelectrochemical energy conversion is based on photoactive semiconductor electrodes which absorb visible light, thereby creating electron-hole pairs which separate in the space charge layer produced at a semiconductor-liquid electrolyte interface. These separated electrons and holes are injected into the electrolyte to drive chemical reduction and oxidation reactions.

Photoelectrochemical cells can be configured to produce electricity (electrochemical photovoltaic cells) or to drive chemical reactions (photoelectrosynthetic cells). Chemical reactions driven uphill in energy (endoergic) produce fuels (for example, splitting of H_2O into H_2 and O_2); chemical reactions can also be driven downhill in energy (exoergic) to produce useful chemicals (for example, reduction of N_2 to NH_3). For the endoergic case, solar energy is converted into chemical energy, while for the exoergic case, solar energy provides the activation energy for chemical reactions.

Photoelectrochemical systems have a high theoretical conversion efficiency (25%); they can be operated with inexpensive polycrystalline and/or amorphous electrodes without drastic loss of efficiency; and simple inexpensive photochemical reactor systems based on photochemical diodes in a slurry- or colloidal-type system can be utilized. However, the major problem preventing the implementation of these advantages is the lack of sufficient photochemical stability in the semiconductor electrode materials that have band gaps in the optimum range (1.0 to 2.0 eV). For electrochemical photovoltaic cells, efficiencies of 12% have been achieved with GaAs electrodes. For photoelectrosynthetic cells, H_2O has been split with simulated sunlight at 1% of efficiency, and N_2 and CO_2 reduction has been demonstrated using visible light and p-GaP electrodes.

The research needs in electrochemical photovoltaic cells include work on (1) theory and models, (2) semiconductor materials with high efficiency and stability, (3) new electrolytes and compatible redox couples, (4) in situ energy storage, (5) toxicology of candidate semiconductor electrodes, and (6) establishment of the relationships between the behavior of single-crystal and polycrystalline electrodes. For photoelectrosynthetic cells, research needs include work on (1) theory and models, (2) catalytic effects and their relationship to electrode overvoltage, (3) new semiconductor electrodes and structures, (4) new and novel photoelectrochemical reactions (such as nitrogen fixation and carbon dioxide reduction), and (5) photochemical diodes (particulate systems) and photocatalytic systems.

Table 2-4. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: PHOTOELECTROCHEMICAL ENERGY CONVERSION

Research	Priority
Electrochemical Photovoltaic Cells (ECPVC)	
1. Development of models and theoretical understanding of ECPVC.	Crucial
2. Development of new electrolytes and compatible redox couples which promote the stability of potential, high efficiency, semiconductor electrodes.	Important

Table 2-4. **SUMMARY OF RESEARCH NEEDS AND PRIORITIES: PHOTOELECTROCHEMICAL ENERGY CONVERSION**
(concluded)

Research	Priority
3. Study of in situ storage in ECPVC.	Important
4. Toxicology—environmental effects of apparently hazardous and toxic materials.	Important
Photoelectrosynthetic Cells (PESC)	
1. Theory and models of PESC.	Crucial
2. Catalytic effects and their relationship to electrode overvoltage.	Important
3. New and novel photoelectrochemical reactions.	Important
4. Photochemical diodes.	Important

SECTION 3.0

BIOLOGICAL SCIENCES

3.1 BIOMASS

To develop a Biotechnology of Biomass Processing for producing fuels and chemicals, basic work is crucially needed in genetics, biochemistry/physiology, and biochemical engineering.

Biomass production could be advanced by adequate research support in plant physiology, agronomy, and tissue culture. It is important that such research be focused on a systems approach; that is, with conversion in view.

For improving the efficiency of conventional fermentation processes, microbiological and biochemical engineering work is crucial. The development of product- and temperature-tolerant strains is crucial. The present energy inefficiency of product recovery should be improved by basic chemical engineering research; optimal control of biological processing is important/crucial.

To bring the processing of lignocellulosic biomass to a commercial level, a long-term application of basic research is crucially required. The mechanism of action of hydrolyzing enzymes is not yet understood. Physiological and biochemical engineering features of mixed culture processing should be investigated. A basic understanding of the genetics of industrial microorganisms and of the possibilities for hybrid construction by gene transfer is lacking. The unconventional engineering features of bioreactors for processing solid biomass require investigation, and there is a lack of information on the fluid dynamic properties of slurries.

Extensive biochemical and genetic work is needed to advance the development of extraction processes for producing oily hydrocarbons and other chemicals from both lower and higher organisms.

Table 3-1. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: BIOMASS

Research	Priority
Biomass Production	
1. Tissue culture.	Crucial
2. Agronomic development (genetics).	Crucial
3. Plant physiology.	Crucial
4. Plant biochemistry and development.	Important
Biomass Conversion	
1. Biological pretreatment.	Crucial
2. Membrane biochemistry.	Crucial

Table 3-1. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: BIOMASS (concluded)

	Research	Priority
3.	Strain development (Genetic Engineering).	Crucial
4.	Product recovery energy efficiency.	Crucial
5.	Novel bioreactor engineering.	Crucial
6.	Immobilized cell research.	Crucial
7.	Biosynthetic pathway manipulation.	Crucial
8.	Process control.	Important/Crucial
9.	Mechanism of cellulose action.	Important
10.	Hemicellulose conversion.	Needed/Important
11.	Pentose metabolism.	Needed/Important
12.	Lignin conversion.	Needed
13.	Xylanase mechanism.	Needed
14.	Slurry rheology.	Needed
	Biomass Extraction	
1.	Plant production of hydrocarbons.	Important/Crucial
2.	Microbial production of chemicals.	Important/Crucial
3.	Biochemistry and genetics of marine microorganisms.	Needed

3.2 PHOTOBIOLOGICAL CONVERSION

Although it is difficult to predict the relative importance of basic research in different areas, it is clear that studies which address metabolism or the relationship between structure and function in photobiological systems (especially the energy transfer processes in photosynthesis) are crucial. Work directed towards understanding the mechanisms and regulation of in vivo energy transducing systems is also crucial during the near term. Research on component stability and coupling mechanisms in in vitro systems is important to crucial over the long term.

Table 3-2. **SUMMARY OF RESEARCH NEEDS AND PRIORITIES: PHOTOBIOLOGICAL CONVERSION**

Research	Priority
1. Primary processes and electron transport.	Crucial
2. Stability of biological systems.	Important
3. Metabolism of biological systems.	Important
Hydrogen production by photosynthetic bacteria	Crucial
4. In vitro systems.	
Short term	Needed
Long term	Important to Crucial

SECTION 4.0

MATERIALS SCIENCES

4.1 METALLURGY AND CERAMICS

The design and fabrication of metal and ceramic components for solar applications must meet critical and often contradictory demands for low cost, high reliability, and long life. Present understanding of fabrication processes and degradation mechanisms are inadequate to insure reproducible performance or to predict service lifetimes with confidence. These are pervasive problems which limit all technological applications of metals and ceramics as well as those in solar energy conversion. Research which is crucial to the improvement of this situation is listed in the table accompanying this section.

Table 4-1. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: METALLURGY AND CERAMICS

Research	Priority
1. Improve the understanding of the processes involved in the reproducible fabrication of metal and ceramic components. These processes include:	Crucial
A. kinetics of nucleation, phase transformations, and solidification;	
B. behavior of fine particles and how their shape and surface properties affect their rheology and subsequent ceramic or powder metallurgy fabrication.	
2. Improve methods to detect flaws in fabricated metal and ceramic components and thereby improve their reliability:	Crucial
A. determine origins of flaws;	
B. develop physical techniques for the nondestructive detection and measurement of flaws.	
3. Improve methods for predicting the degradation of metal and ceramic components in service:	Crucial
A. improve the understanding of atomistic mechanisms at the tip of a growing crack;	
B. model complicated chemical reaction processes in multiphase, multicomponent systems.	
4. Improve the nonequilibrium, nonlinear thermodynamic theory required to describe the processes in A-C above.	Important

4.2 MATERIALS CHEMISTRY

Major research efforts should be carried out in materials chemistry to elucidate mechanisms of degradation in solar-stressed environments that reduce the solar system performance, in order to (1) guide modifications of materials to minimize the effect of the detrimental processes; (2) understand the influences of structure, bonding, and composition that provide stability; (3) devise materials preparation and fabrication processes that yield the desired chemical, electronic, physical, or mechanical properties; and (4) devise new experimental techniques to study and/or measure the important materials properties.

In summary, a number of studies are crucial, important, and needed for impacting solar energy conversion technologies. These are listed in the accompanying table. It is crucial that the studies be carried out on the most promising materials to elucidate the synergistic effects of solar stresses such as UV, temperature, atmospheric gases and pollutants, daily and annual thermal cycles, etc.

In addition to those people contacted, as given in Appendix B, the information in this section has been assembled using several reference documents (Call 1979; Somorjai et al. 1977; U.S. DOE 1979b; Solar Optical Materials Program Activity Committee 1979; Solar Glass Coordinating Committee 1979; Pohlman and Staehle 1979).

Table 4-2. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: MATERIALS CHEMISTRY

	Research	Priority
1.	Work on the most promising materials for potential application when exposed to solar-stressed environments.	Crucial
2.	Study enhanced stability/reactivity resulting from interfacial contact between different materials.	Crucial
3.	Elucidate mechanisms of degradation reactions at s/s, s/l, and s/g interfaces.	Crucial
4.	Elucidate mechanisms of photoenhanced degradation of polymers and ion transport in transmitting materials.	Crucial
5.	Study gas/solid reactions and co-chemisorption processes at atmospheric pressure.	Crucial
6.	Study diffusion in coatings and thin films including atom transport and accumulation at grain boundaries.	Crucial
7.	Understand bonding, compositional, and structural relationships in adhesion.	Crucial
8.	Understand reactions at s/l interfaces.	Crucial
9.	Work on the stability of polycrystalline materials.	Important

Table 4-2. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: MATERIALS CHEMISTRY (concluded)

	Research	Priority
10.	Understand diffusion and segregation at grain boundaries.	Important
11.	Study nucleation and growth at interfaces.	Important
12.	Determine interfacial effects on optical properties.	Important
13.	Understand adhesion of s/s interfaces, including polymer/ metal oxide(s).	Important
14.	Study adhesion of dust onto transmitting materials.	Important
15.	Conceive and test theoretical models of polycrystalline systems.	Needed
16.	Conceive and test theoretical models of atomic forces in adhesion.	Needed
17.	Study growth or modification processes to alter properties of films, coatings, glasses, and polycrystalline materials.	Needed
18.	Develop advanced instrumentation for preparing new or modifying existing materials.	Needed
19.	Characterize interfacial properties of polycrystalline materials.	Needed
20.	Develop equipment to detect incipient stages of diffusion, segregation, chemisorption, etc.—processes that cause changes in properties.	Needed

4.3 SOLID STATE PHYSICS

Solid state physics plays a very important role in solar energy conversion. One of the solid state energy conversion techniques, photovoltaics, is currently being actively investigated by Energy Technology (ET). But there are other energy conversion technologies that need to be studied from both basic and applied points of view. It is crucial to develop a research program in solid state energy conversion technologies, as they will open alternate avenues for solar energy conversion. Further, some of them may be particularly suited for certain applications. For example, thermoelectrics may be more suitable than photovoltaics in solar total energy systems or as a topping cycle for a solar steam power plant. It is crucial to conduct a broad program of research in thermal and optical properties of materials in support of energy conversion technologies. It is crucial to conduct a comprehensive empirical and theoretical search to identify promising materials for solid state energy conversion. It is crucial to develop an experimental research program in new semiconductor materials such as amorphous semiconductors or organic semiconductors. This will open up interesting possiblities for thermoelectric and other solid state energy conversion processes. In fact, it may be possible to take a fresh approach to photovoltaics. Some scientists believe that a radical reduction in cost of solar cells could be achieved by an imaginative research program to uncover a very cheap thin-film material that has optical and electrical properties suited for solar cells. In addition, there are several areas of basic and applied research which have to be pursued in support of ET activity. The crucial ones are studies of self-compensation, basic properties of reactive melts, and a diagnostic study of plasma used in formation of thin films. Chemical thermodynamics and kinetic studies of gas phase reactions, compound formation at interfaces, thin-film nucleation and electromigration, and thermodynamic studies of semiconductors are important for further solar cell improvements.

Table 4-3. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: SOLID STATE PHYSICS

Research	Priority
1. Solid state energy conversion processes; thermal and optical properties of semiconductors; thermodynamic studies of semiconductors.	Crucial
2. Theoretical approach to identify new materials for energy conversion.	Crucial
3. Experimental research on new semiconductor materials.	Crucial
4. Theory of hetero- and homojunctions.	Important
In support of ET program in PV	
1. Self compensation studies; diagnostic study of plasma in formation of thin films; basic properties of high-temperature reactive melts.	Crucial
2. Chemical thermodynamics and kinetic studies of gas phase reactions; compound formation at interfaces; nucleation and growth of thin films; electromigration.	Important
3. Electron affinity measurements, doping, and solubility in III-V compounds.	Needed
In support of Photoelectrochemical Energy Conversion Research	
1. Research involving electrochemical photovoltaic cells (ECPVC), including studies of:	
A. semiconductor materials, with high conversion efficiency and long-term stability;	Crucial

Table 4-3. **SUMMARY OF RESEARCH NEEDS AND PRIORITIES: SOLID STATE PHYSICS** (concluded)

Research	Priority
B. polycrystalline/single-crystal electrodes.	Crucial
2. New semiconductor electrodes and structures for photo-electrosynthetic cells.	Crucial

SECTION 5.0

ENGINEERING AND MATHEMATICS

5.1 ENGINEERING

There is a vital need to conduct engineering research in support of DOE programs in solar energy. It is important to solve hydrodynamic problems related to salty solar ponds. Research in heat and fluid mechanics is important in order to support solar collector development. Several research problems are important to solar cooling, such as endothermic cooling methods and dessicant cooling. Despite common belief, several basic problems, such as multizone convection, need to be solved in support of passive solar technology.

Table 5-1. **SUMMARY OF RESEARCH NEEDS AND PRIORITIES: ENGINEERING**

	Research	Priority
1.	Hydrodynamic problems in solar ponds.	Important
2.	Heat transfer and fluid dynamics problems in collectors.	Important
3.	Solar cooling—endothermic and desiccant cooling, chemical heat pumps.	Important
4.	Multizone convection, soil heat conduction in support of passive solar technology.	Needed

5.2 MATHEMATICS

As the basic research needs of the solar community are better defined, it is expected that mathematical and numerical modeling will play an increasingly important role in accelerating the development of these technologies. Although the mathematical and computer science research communities are actively participating in the development of other energy technologies, they have not been made aware of the analytical and computational needs of the solar research community. For this reason, a DOE-sponsored workshop to better define the problem areas is considered important. It is also important to support additional research in the area of finite difference and finite element techniques for partial differential equations and other closely related areas, such as the numerical solution of large systems of linear and non-linear equations. Additional research is needed in the areas of numerical solution of ordinary differential equations and integral equations, stability analysis, asymptotic analysis and perturbation methods for partial differential equations, nonlinear and stochastic optimization techniques, optimal control techniques, statistical and time series descriptions of solar insolation data, and the development of efficient simulation methods.

Table 5-2. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: MATHEMATICS

Research	Priority
1. Workshop on mathematical and computational needs.	Important
2. Numerical solution of partial differential equations and related areas.	Important
3. Numerical solution of ordinary differential equations and integral equations.	Needed
4. General applied mathematical techniques such as stability analysis, asymptotic analysis, and perturbation methods.	Needed
5. Nonlinear and stochastic optimization techniques, optimal control problems.	Needed
6. Statistical and time series descriptions of solar insolation and wind data.	Needed
7. Efficient simulation methods.	Needed

SECTION 6.0

ADVANCED ENERGY RESEARCH PROJECTS

AERP is currently supporting high-risk innovative concepts and is playing a very important role in the DOE program. However, the magnitude of effort is much too small to meet the needs of solar energy, which is in dire need of new concepts. It is therefore crucial to enlarge the activity of supporting innovative research in solar energy. Presently, there is a gap between basic energy research as supported by BES and technological development as supported by ET. It is crucial that the area of applied science, particularly applied physics, be covered by AERP. There also is a gap in energy conversion processes, because there is no branch in ER which provides the opportunity for sustained development of new concepts in these areas. Examples are thermoelectrics, ferroelectrics, thermionics, etc. It is crucial to develop the area of energy conversion sciences, particularly the ones dealing with high temperatures, as they may hold the key for making solar technology viable by the turn of the century. It is suggested that activity in these two areas—applied science and energy conversion—be brought into focus, perhaps by creating branches for each within the AERP division.

Table 6-1. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: ADVANCED ENERGY RESEARCH PROJECTS

Research	Priority
1. Support of high-risk research as in the past, but on a larger scale to meet solar needs.	Crucial
2. Support of applied science research, perhaps as a branch (particularly applied physics).	Crucial
3. Support of energy conversion research, perhaps as a branch.	Crucial

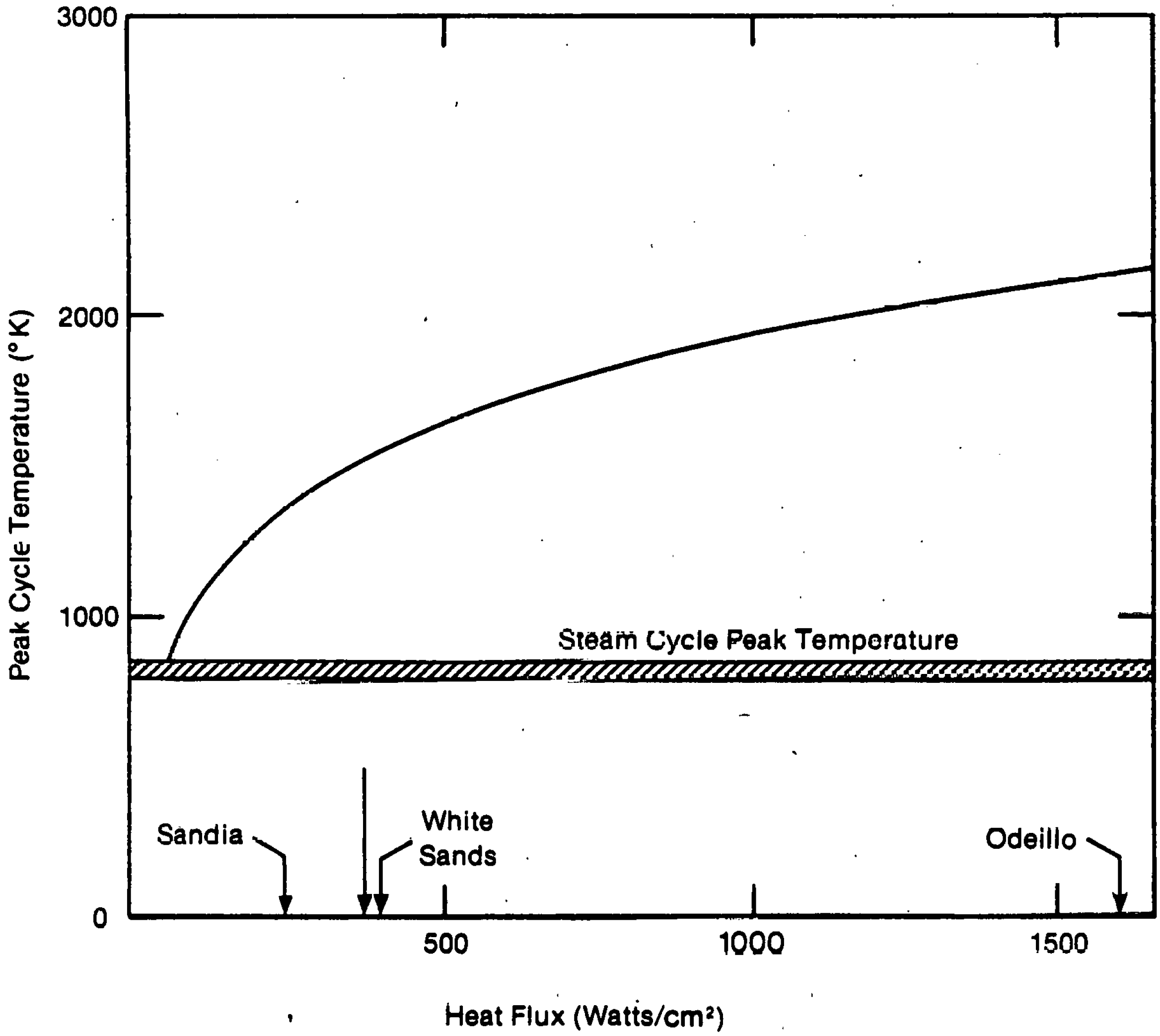

Figure 6-1. Peak Cycle Temperature Achievable by Concentrating Solar Flux

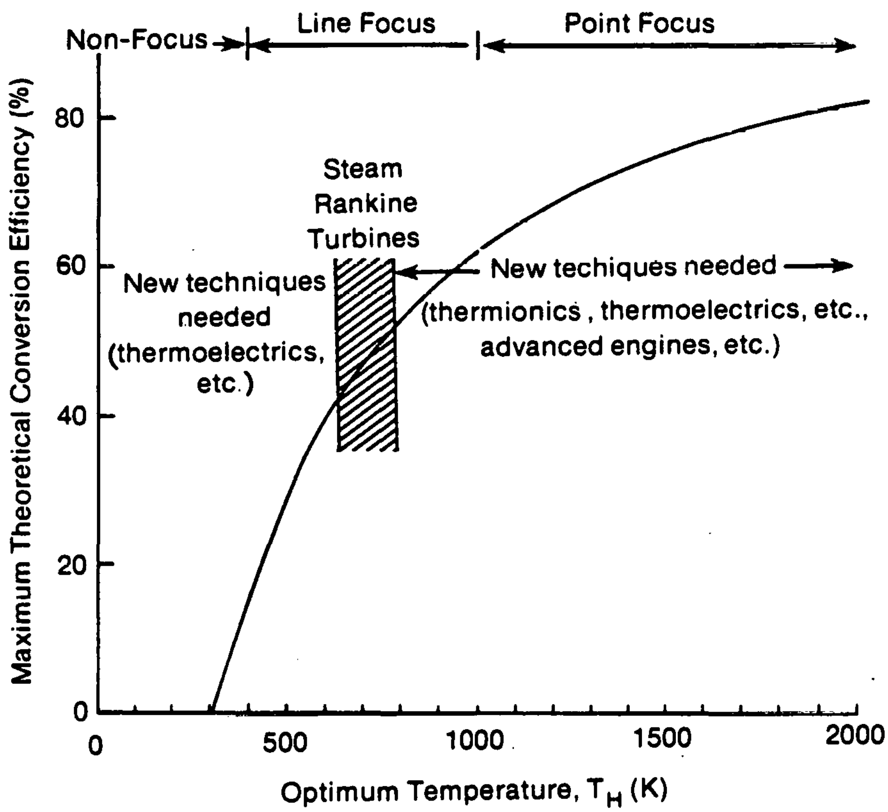

Figure 6-2. Maximum Theoretical Conversion Efficiency as a Function of Achievable Collector Temperatures

SECTION 7.0

BEHAVIORAL AND SOCIAL SCIENCES

7.1 INTRODUCTION

An office of Science and Technology Policy working group recently concluded that "A notable weakness (in DOE research) is the tendency to view obstacles to adoption of new energy systems as purely technological. Important obstacles to the adoption of new energy systems or expansion of existing ones will increasingly be recognized to be to some degree political, sociological, economic, institutional, and environmental in character. Research which could assist in addressing these issues is virtually nonexistent within the DOE" (U.S. Executive Office of the President 1978, p. 9).

This finding sets the stage for the following description of generic areas of need for basic and applied Behavioral and Social Science research that would support solar energy development. These needs can be addressed through research undertaken in the traditional disciplines of the Behavioral and Social Sciences: sociology, political science, economics, and psychology; and in newer, applied, and multidisciplinary fields such as environmental studies and policy sciences.*

We have organized research needs by broad area of research rather than by discipline, because in most cases several disciplines have made efforts to address the same issue and because many social problems cannot be addressed through the perspective of a single discipline. For example, even in the case of "basic" research on consumer decision making, psychologists, sociologists, and economists have attempted to develop explanatory and predictive theory. We have not distinguished between basic and applied social science research because precise distinctions are both difficult to make and likely to be irrelevant for present purposes. Research needs are divided into six subject areas: Behavior of Individuals; Behavior of Organizations and Communities; Political, Social, and Economic Processes; Social and Economic Impacts; Policy Analysis; and Research Methods and Conceptual Bases for Research.

7.2 BEHAVIOR OF INDIVIDUALS

By the year 2000, a substantial portion—perhaps 25%—of solar energy will be generated by technologies purchased by individual consumers. If public agencies desire to accelerate the acceptance of these technologies, they need to understand what influences individual energy choices. In particular, it is crucial that analyses of the consumer decision process be conducted, including the effect of external factors on consumer decisions, product attributes, risk and uncertainty, and value and use of information. Research is needed that focuses on the effect of individual lifestyle or changing lifestyle on individual energy choice.

*Definitions of the social sciences can be found in Appendix A.

Table 7-2.[a] SUMMARY OF RESEARCH NEEDS AND PRIORITIES: BEHAVIOR OF INDIVIDUALS

Research	Priority
1. Analysis of the consumer decision process, including the effect of external factors, on consumer decisions, product attributes, risk and uncertainty, and value and use of information.	Crucial
2. The effect of individual lifestyle or changing lifestyle on individual energy choice.	Needed

[a]There is no Table 7-1. The tables were numbered so that they would coincide with section numbers.

7.3 BEHAVIOR OF ORGANIZATIONS AND COMMUNITIES

The bulk of energy technology purchases are made by organizations: government units, industrial and commercial firms, utilities, etc. Despite their importance in determining the extent of solar energy use over the next decades, little is known about how and why organizations decide to adopt or reject new technological products, particularly new energy supply technologies. It is crucial that research be supported that analyzes the significance that external factors and organizational strategies and objectives have on energy supply choices. It is important to expand and improve economic decision models, particularly through continued development of generic models of utility company behavior, and to identify the influence that risk and uncertainty have on industry and utility decisions. Finally, research is needed that would analyze the impact of bureaucratic incentives, organizational structure, and objectives on decisions to adopt and use new energy technology. In addition, research is needed on the value and use of information in community and organizational decision making.

Table 7-3. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: BEHAVIOR OF ORGANIZATIONS AND COMMUNITIES

Research	Priority
1. Assessment of the significance of external factors on organizational and community energy supply decisions.	Crucial
2. Analysis of the influence that organizational strategies and objectives have on energy supply choices.	Crucial
3. Improvement and expansion of economic decision models, particularly through continued development of generic models of utility company behavior.	Important
4. Identification of the influence of risk and uncertainty on industry and utility decisions.	Important

Table 7-3. **SUMMARY OF RESEARCH NEEDS AND PRIORITIES: BEHAVIOR OF ORGANIZATIONS AND COMMUNITIES** (concluded)

Research	Priority
5. Analysis of the impact of bureaucratic incentives, organizational structure, and objectives on decisions to adopt new energy technology.	Needed
6. The value and use of information in community and organizational decision making.	Needed

7.4 POLITICAL, SOCIAL, AND ECONOMIC PROCESSES

This category of research focuses on a very broad range of socioeconomic and political processes such as the diffusion of new technologies, shifts from centralized to decentralized energy economies, and energy supply economics. It is crucial that better understanding of the factors that influence the rate and pattern of diffusion of new technologies (market penetration) be achieved, that the implications of a major shift toward a decentralized energy economy for the social system and for social values be identified, and that the impact of introducing renewable energy technologies on conventional supply economics be understood. Analysis of the energy policy-making process itself is important, including identification of who makes energy policy decisions, the timing of such decisions, and the information needs of decision makers. It is also important that improved measures of social costs and benefits be developed and used in energy policy making. Finally, analysis of the roles of various levels of government (federal, state, local) for development and implementation of energy policy is needed.

Table 7-4. **SUMMARY OF RESEARCH NEEDS AND PRIORITIES: POLITICAL, SOCIAL, AND ECONOMIC PROCESSES**

Research	Priority
1. Investigation of the factors that influence the rate and pattern of diffusion of new technologies (i.e., market penetration).	Crucial
2. Analysis of the implications of a major shift towards a decentralized energy economy for the social system and for social values.	Crucial
3. Impact of conventional energy supply economics on the introduction of renewable energy technologies.	Crucial
4. Measurement and use of social cost and benefit information in energy policy making.	Important

Table 7-4. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: POLITICAL, SOCIAL, AND ECONOMIC PROCESSES (concluded)

Research	Priority
5. Analysis of the energy policy-making process, with emphasis on who makes energy policy decisions, the timing of such decisions, and the information needs of the decision makers.	Important
6. Analysis of the roles of various levels of government (federal, state, and local) for development and implementation of energy policy.	Needed

7.5 SOCIAL AND ECONOMIC IMPACTS

Research in this area would improve public policy outcomes by increasing the accuracy of assessments of raw material demands, environmental impacts, level and skill mix of labor requirements, and other social and economic impacts of particular energy technologies. Crucially needed research would assess, on a disaggregated basis (e.g., regionally), the social and economic impacts of developing alternative energy sources. Important research would assess the environmental impacts of solar energy versus conventional energy sources, while needed research would identify existing end-use requirements for energy and potential applications for solar technologies.

Table 7-5. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: SOCIAL AND ECONOMIC IMPACTS

Research	Priority
1. Assessment of the social and economic regional impacts of developing alternative energy sources.	Crucial
2. Assessment of the environmental impacts of solar energy versus conventional energy sources.	Important
3. Identification of existing end-use requirements for energy and potential applications for solar technologies.	Needed

7.6 POLICY ANALYSIS

This area of research focuses on assessment of alternative federal, state, and local government actions intended to influence the development and application of solar technologies. Research topics should expand our knowledge of the consequences of different courses of government action and develop improved analytical methods for assessing their costs and benefits. It is crucial that assessments of the effectiveness of different mixes of policy instruments and practices such as taxation, regulation, procurement, demonstration, R&D, and information dissemination be conducted. It is also crucial that the effects of public utility commission regulatory practices on solar technology utilization be assessed. Research is needed that would analyze the influence of policy implementation on the effectiveness of solar energy policies, and that would evaluate specific programs intended to influence the development and application of solar energy.

Table 7-6. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: POLICY ANALYSIS

Research	Priority
1. Analysis of the actual and potential government role in the development and application of new energy technologies.	Crucial
2. Assessment of the impact of public utility commission regulatory practices on solar technology utilization.	Crucial
3. Analysis of the influence of policy implementation, in contrast to policy design, on the effectiveness of solar energy policies.	Needed
4. Increased evaluation of specific programs intended to influence development and application of solar energy.	Needed

7.7 RESEARCH METHODS AND CONCEPTUAL BASES FOR RESEARCH

This category of research calls for the development of improved analytical and methodological tools to address the research needs outlined in earlier sections. A proportion of the BES research budget should be allocated to such studies as an investment in the quality and utility of future research products. It is important that efforts be undertaken to improve the theory and methods of existing energy-economy analyses and models, and to incorporate new energy technologies into these models. Research methods are needed that would improve the evaluation of energy development and application programs, social impact assessments, and the understanding of relationships between individual attitudes and opinions and subsequent behavior. There is also a need to increase the multidisciplinary character of existing socioeconomic databases and models.

Table 7-7. SUMMARY OF RESEARCH NEEDS AND PRIORITIES: RESEARCH METHODS AND CONCEPTUAL BASES FOR RESEARCH

Research	Priority
1. Improved analysis of energy-economy interactions and incorporation of new energy technologies.	Important
2. Development of improved research methods for evaluating energy development and application programs and for depicting more accurately relationships between individual opinions and attitudes and subsequent behavior.	Needed
3. Increased multidisciplinary character of existing socioeconomic databases and models.	Needed

SECTION 8.0

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APPENDIX A

DESCRIPTION OF SOCIAL SCIENCE DISCIPLINES

The following description of the five central social science disciplines is taken from Knowledge Into Action: Improving the Nation's Use of the Social Sciences (NSF 1969).

What Are the Social Sciences?

The social sciences are intellectual disciplines that study man as a social being by means of the scientific method. It is their focus on man as a member of society, and on the groups and societies that he forms, that distinguishes the social sciences from the physical and biological sciences.

Historically, five social sciences have been regarded as central: anthropology, economics, political science, psychology, and sociology. Other important fields that deal with social phenomena are: demography, history, human geography, linguistics, and social statistics.*

Anthropology and sociology are somewhat difficult to distinguish from each other. Both study the societies in which man lives; that is, the social forms and structures within which individual and group behavior takes place. Anthropology (which includes social anthropology, archaeology, physical anthropology, and the linguistics of preliterate cultures) studies the varied physical and cultural characteristics of man throughout the world. Traditionally, its attention has been directed to primitive cultures. But a number of anthropologists now study the cultures of industrialized societies including, of course, the United States; and anthropologists have produced fruitful work on such important contemporary problems as poverty, ghetto life, minority groups, and mental health.

Sociology is often called the science of society. In contrast to anthropology, sociology has always concentrated on the structure and functioning of groups within literate societies. Sociologists study such features of society as the family, rural and urban life, race relations, crime, and occupational groupings.**

Economics is the study of the allocation of scarce productive resources among competing uses. Within this framework, economists engage in theoretical and empirical research on both macroeconomic subjects (reaching and maintaining full employment, avoiding inflation and deflation, understanding and promoting economic

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*Branches of psychology and anthroplogy often fall in the biological sciences as well as the social sciences. Similarly, parts of historical inquiry properly belong in the humanities. We refer the reader to the forthcoming report of the Behavioral and Social Survey Committee for an exposition of the nature of these disciplines, their development, and the kind of work that each does. We also leave to that report the tasks (1) of describing the hybrid fields that exist within the social sciences, and between the social sciences and the natural sciences; and (2) of distinguishing between behavioral sciences and social sciences.

**Social psychology is an important subfield that sociology shares with psychology. Social psychology studies the behavior of man as influenced by the groups to which he belongs.

growth, analyzing fiscal and monetary policies, defining balance and imbalance in international payments) and on microeconomic subjects (market pricing, monopolies, manpower, labor markets, union movements, farm issues, and problems resulting from inequalities in income distribution and poverty).

Psychology studies the nature and organization of mental processes in man. Psychologists deal with man's mental abilities and aptitudes: his capacities for learning, for thinking, for emotional expression, and for motivation. Psychologists have developed intelligence and aptitude tests for a great variety of uses. They work on problems of learning in education, personnel selection in industry, and clinical assessment in mental illness, among many others.

Political Science investigates the ways in which men govern themselves. It is concerned with the goals of the political system, the structural relationships in that system, the patterns of individual and group behavior which help explain how that system functions, and the policy outputs as well as behavioral consequences of that system. Political scientists study a variety of phenomena involved in the process of government, including political parties, interest groups, public opinion and communication, bureaucracy, international relations, and administration.

APPENDIX B

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Mitchell, Kim; Solar Energy Research Institute
Rose, A.; Exxon Corporation
Stone, Jack; Solar Energy Research Institute
Surek, Tom; Solar Energy Research Institute
Wagner, Sigurd; Solar Energy Research Institute
Williams, R.; RCA

Engineering, Mathematics, and Geosciences

Engineering

Bohn, Mark; Solar Energy Research Institute
Butts, Sheldon; Solar Energy Industries Association
Duffie, Jack; University of Wisconsin, Madison
Eibling, James; Battelle Memorial Institute
Jayadev, T. S.; Solar Energy Research Institute

*More than 300 scientists participated in solar materials and surface science workshops as given in the original documents referenced at the end of Section 8.

Kreith, Frank; Solar Energy Research Institute
Lof, George; Colorado State University and Solaron Corporation
Neper, Don; Los Alamos Scientific Laboratory
Rabl, Ari; Solar Energy Research Institute
Telkes, Maria; American Technological University
Yellot, John; Yellott Solar Energy Labs

Mathematics

Backmaster, John; Ohio State University
Cohen, Joel; Solar Energy Research Institute and University of Denver
Davis, Paul; Consultants Computation Bureau
Golub, Gene; Stanford University
Hachtel, Gary; IBM Thomas J. Watson Research Center
Kahan, Bill; University of California, Berkeley
Keller, Herb; California Institute of Technology
Thompson, Don; Society for Industrial and Applied Mathematics
Wendroff, Burton; Los Alamos Scientific Laboratory

Advanced Energy Projects

Connolly, John S.; Solar Energy Research Institute
Drummond, James; Power Conversion Technologies
Fitzpatrick, Gary; Rasor Associates
Jayadev, T. S.; Solar Energy Research Institute
Winston, Roland; University of Chicago

Behavioral and Social Sciences

Political Science

Brunner, Roland; Institute for Public Policy Studies, University of Michigan
deLeon, Peter; Solar Energy Research Institute
Kash, Don; U. S. Geological Survey
LaPorte, Todd; Institute of Governmental Studies, University of California, Berkeley
Merrow, Edward; The Rand Corporation
Mihalka, Michael; The Rand Corporation
Teich, Albert; Technology and Public Program, George Washington University
White, Jack; Special Assistant to the Assistant Director for R&D, Environmental Protection Agency

Psychology/Social Psychology/Marketing

Burns, Barbara A.; Solar Energy Research Institute
Hutton, Bruce; University of Denver
McNeill, Dennis; University of Denver
Stern, Paul; Institute for Social and Policy Studies, Yale University
Unseld, C. T.; Solar Energy Research Institute

Sociology

Farhar, Barbara; Solar Energy Research Institute
Freudenburg, William, F.; Washington State University
Piernot, Craig; Solar Energy Research Institute

Environmental Studies

Caputo, Richard; Jet Propulsion Laboratory
Holdren, John; Energy and Resources Group, University of California, Berkeley
Lawrence, Kathryn; Solar Energy Research Institute

Economics

Chapman, L. D.; Cornell University
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Kahn, Edward; Lawrence Berkeley Laboratory
Mount, Timothy; Cornell University
Peterson, H. Craig; Utah State University

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report identifies, describes, and recommends priorities for basic research important to the future development of solar energy. In response to a request from the U.S. Department of Energy, SERI surveyed more than 120 leading scientists who were engaged in or knowledgeable of solar-related research. SERI scientists relied heavily on the opinions of scientists polled, but weighted their own recommendations and opinions equally. The result is an amalgam of national scientific opinion representing the views of key researchers in relevant disciplines and of SERI staff members. The scientific disciplines included in the report are: chemistry, biology, materials sciences, engineering and mathematics, and the social and behavioral sciences. Each discipline is subdivided into two to five topical areas and, within each topical area, research needs are described and ranked according to the priorities suggested in the survey. Three categories of priority were established: "crucial," "important," and "needed." A narrative accompanying the description of research needs in each topical area discusses the importance of research in the area for solar energy development and presents the bases for the priority rankings recommended.

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