File 1.1.2

11.2

1114

SOLAR ENERGY RESEARCH AND DEVELOPMENT:

FEDERAL AND PRIVATE SECTOR ROLES

REPORT OF THE ENERGY RESEARCH ADVISORY BOARD

Prepared by the

SOLAR R&D PANEL

September 1982

Department of Energy
Washington, D.C. 20585

October 12, 1982

ENERGY RESEARCH ADVISORY BOARD

Honorable W. Kenneth Davis
Deputy Secretary
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Ken:

I am pleased to forward the Energy Research Advisory Board's (ERAB) Report on Solar Energy Research and Development: Federal and Private Sector Roles, prepared by the Solar R&D Panel. This Report, unanimously approved by the ERAB on September 9, 1982, constitutes our response to the request in your March 15, 1982 charge to the Board to undertake a study of the solar energy program that would help the Department define the most effective Federal program, given the limited resources that will probably be available, and to help ensure that future Federal investments will provide the long-term technical base needed for a healthy and competitive national effort.

The Solar R&D Panel was composed of individuals from industry, academia, and State government. The Panel heard from over 70 solar energy experts in a series of meetings intended to take advantage of a broad range of available experience and perspectives, and availed itself of selected technical literature and special staff studies as well. ERAB examined many R&D options and felt that its findings and recommendations constitute a Federal program which should be sufficient to provide the long-term scientific and technical base needed to advance solar technologies.

I trust that these findings and recommendations will be of use to the Department in formulating solar R&D policy.

Sincerely,

Louis H. Roddis, Jr.
Chairman
Energy Research Advisory Board

Enclosure

Department of Energy
Washington, D.C. 20585

ENERGY RESEARCH ADVISORY BOARD
September 7, 1982

Louis H. Roddis, Jr.
Chairman
Energy Research Advisory Board

Dear Lou,

I am pleased to submit the Final Report of the Solar Energy Panel to the Energy Research Advisory Board for consideration on September 9. We hope that final action on the report by ERAB will complete our duties in time for assistance in budget preparation as the Deputy Secretary of Energy has requested.

As you know, we had an extremely tight schedule to meet, and I would like to thank the Panel for their dedication and cooperation as we sorted through vast quantities of information concerning many diverse technologies. Also the Panel as a whole was very impressed with the assistance we received from our Executive Secretary, the ERAB staff, staff of the Assistant Secretary for Conservation and Solar Energy, Oak Ridge National Laboratory, the Solar Energy Research Institute, Sandia National Laboratory, and the Jet Propulsion Laboratory and the many witnesses we heard, most of whom gave us careful, well-reasoned presentations on very short notice.

Sincerely,

Vicki

Victoria J. Tschinkel
Chairman
Solar R&D Panel

TABLE OF CONTENTS

ABSTRACT

The Energy Research Advisory Board convened a Solar R&D Panel to determine the status of the solar industry and solar R&D in the United States and to recommend to DOE appropriate roles for the Federal and private sectors. The Panel's report acknowledges the new Administration policy reorienting the Federal role in energy development to long-term, high-risk, high payoff R&D, and leaving commercialization to the private sector. The Panel's recommendations are further predicated on an assumption of continued, substantially reduced funding in the near-term.

The Panel found that solar energy technologies have progressed significantly in the past ten years and represent a group of highly promising energy options for the United States. However, it also found the solar industry to be in a precarious condition, due to the risks of initiating a new technology, current economic conditions, fluctuating energy demand and prices and uncertain Federal tax and regulatory policies. The Business Energy and Residential Tax Credits are essential to the near-term health of the solar industry. Commercialization has already begun for some solar technologies; for others, decreases in Federal funding will result in a slowdown or termination.

The primary Federal roles in solar R&D should be in support of basic and applied research, high-risk, high payoff technology development and other necessary research for which there are insufficient market incentives. The Federal Government should also move strongly to transfer technology to the private sector for near-commercial technologies. Large demonstration and commercialization projects cannot be justified for Federal funding under current economic conditions. These should be pursued by the private sector.

The Panel examined seven technology areas and made specific findings and recommendations for each:

Solar Related Basic Research:

Basic research is important for all solar technologies. DOE, through both the Office of Energy Research and the AS/CE, should especially support basic research in photochemistry, photosynthesis, and materials. Basic research in materials should emphasize three key areas--degradation, interfaces and stable synthetic materials with good optical properties.

Photovoltaics:

PV is a near ideal candidate for the Administration's energy policy of Federal support for high-risk, high payoff R&D. Highest payoff is expected from R&D in compound semiconductor and silicon thin film solar cells. Other promising areas include single-junction crystaline thin film cells, advanced multi-junction concepts and amorphous silicon. DOE should support an innovative concepts R&D program in areas which have potential for major breakthroughs. Support for the Sacramento Municipal Utility District (SMUD) 1 MWe demonstration project should be discontinued.

Solar Thermal:

Central receiver technologies are rapidly becoming ready for transfer to the private sector, as are parabolic troughs. Federal support in these areas should be limited to operational testing including participation in the testing of the Solar One Central Receiver facility at Barstow, California. DOE should turn its emphasis to parabolic dish technology. The hemispherical bowl program should be dropped. Solar pond technology should continue to be monitored by DOE but no pilot plants should be Federally funded at this time. Solar thermal related basic R&D should be more sharply focused on advanced materials with good optical, thermal and structural properties and advanced low-cost structures.

Wind:

DOE should continue to support data gathering and analysis of the MOD 2 array in Goldendale, Washington, and the WTS-4 machine at Medicine Bow, Wyoming. Small wind machine support by DOE should be phased out by 1985. Federally maintained wind machine test facilities should continue to be operated, contingent upon industry paid support. Advanced wind research in such areas as wind distribution, aerodynamics and structural response should continue to be supported by DOE. Support for the MOD-5 program by the Federal Government is only recommended if FY'83 budget levels are at approximately the FY'82 level. Federal support for large wind machines should be phased out after MOD-5.

OTEC:

DOE should complete its involvement in the preliminary OTEC design program but should not participate in any further OTEC demonstrations. A modest technology base activity should be continued by DOE however, to support private efforts.

Biomass Energy:

The current DOE biomass energy program requires sharper focus and a comprehensive R&D framework. Basic research in biotechnology needs to be extended into areas directly related to solar energy. DOE's primary role in biomass should be in research which expands the resource base, and secondarily in expanding the technology base for conversion, especially lignocellulosic materials from forests. The environmental impacts of biomass may be significant and also deserve continued Federal R&D support.

Buildings Solar Energy Research:

R&D leading to improved energy performance in buildings should be given higher priority by DOE. DOE should continue testing of the energy performance of buildings. All DOE research and development in solar energy and conservation in buildings should be combined into one organizational unit. DOE R&D should focus on new materials, new systems for heating and cooling, heat and mass transfer and lighting in buildings. DOE should take the lead in initiating with industry the establishment of an industry-supported Buildings Energy Research Institute.

I. EXECUTIVE SUMMARY

The Federal Government has played the dominant role in the development of solar energy technologies in the United States. Federal solar programs grew rapidly in the 1970s, and tax credits and other favorable regulatory provisions added incentives to the growth of an expanding solar energy industry.

In 1981, the Administration redefined the Federal role in energy development. The new policy emphasizes long-term, high-risk, potentially high-payoff R&D for which market incentives are not sufficient. Commercialization is left to industry as solar technologies become competitive in the marketplace.

The transition to this new policy resulted in a reduction in Federal funds from $570 million in 1980 to $280 million in 1982, (see Appendix F) a termination of some programs, and a change in the focus of others. As these changes were implemented, concern was raised in Congress regarding the content of the remaining solar program, and, separately, regarding the ability and incentive of industry to assume leadership for continued solar developments.

In response to these concerns, the Deputy Secretary of Energy requested that the Chairman of the Energy Research Advisory Board (ERAB) convene a Panel to recommend future Federal activities in solar R&D. Specifically, the Board was asked to "undertake a study of the solar energy program that would help the Department define the most effective Federal program given the limited resources that will probably be available...(and to) help ensure that future Federal investments will provide the long-term scientific base needed for a healthy and competitive national effort."

The Solar R&D Panel was composed of individuals from industry, academia, and state government. In conducting this study, the Panel availed itself of selected technical literature, special staff studies, and met on five separate occasions with more than 70 solar energy experts from industry, universities, research institutions, and government in order to take advantage of a broad range of available experience and perspectives. The Panel's report was reviewed and approved at the September 9th, 1982 meeting of the Energy Research Advisory Board.

The Panel's charter was to consider four issues indicated in the Deputy Secretary's letter:

1. In each solar technology, what specific research objectives should be supported by the Federal Government?
2. What is the present ability and incentive of industry to assume leadership for continued solar development?
3. What mechanisms may be needed to ensure an efficient transfer of solar technology developed by government to the private sector?
4. What is the appropriate Federal role with respect to each solar technology?

Several factors provided the context for the Panel's study. The Panel acknowledged the change in the Administration's policy regarding the role of Federally-supported programs in energy. The Panel did not specifically address the question of an appropriate Federal solar R&D budget level, by itself, or in relation to R&D budget levels in other energy technologies. Nevertheless, the Panel's deliberations regarding an appropriate DOE solar R&D program assumed a continued limited availability of financial resources for the program, at approximately the 1982 appropriated budget level.

The Panel directed its work to pragmatic assessments of the state of each solar technology, R&D opportunities, the state of the industry and existing market conditions, and examined prospects for transfer of knowledge from the Federal Government to the private sector. It established a number of sub-panels and reviewed each solar technology on a case-by-case basis in order to establish findings and recommendations which would define an appropriate Federal role with respect to the state of the technology and the specific technical and economic circumstances which each solar industry confronts.

The Panel examined a broad number of R&D options in each of seven solar technologies including: photochemistry and basic research, photovoltaics, thermal, wind, OTEC, biomass, and buildings technologies. The Panel found a wide spectrum of promise and potential. Some technologies are commercially available or ready for commercialization and do not require Federal support; some, close to commercialization, need minimal support; some show little promise, and Federal support should be discontinued. Basic and applied research requires continued stable Federal support over the long term. Overall, the Panel believes its findings and recommendations constitute a worthwhile Federal program sufficient to provide the long-term scientific and technical base needed to gradually advance solar technologies.

The findings and recommendations are followed, when appropriate, by page numbers referring the reader to the place in the report where the subject is discussed.

<u>General Findings and Recommendations</u>

- Solar energy technologies--some of which have been important at the regional level for many years--represent a series of highly promising energy options for the United States, offering both demonstrated technical feasibility and a secure, long term, renewable resource base to draw from. This promise is constrained by the physical properties of different solar resources characterized by varying regional and temporal availability, and by the diffuse and diurnal nature of the solar flux. These characteristics make the current economics of many solar technologies unattractive, and frame the challenge for R&D programs.

- Solar energy technologies have progressed significantly in the last 10 years. This progress should continue if the roles of the Federal Government and the private sector are clearly and appropriately defined. (pp. 84-85)

- In assessing the ability and incentive of industry to assume leadership for continued solar development, the Panel finds that the United States solar industry is in a precarious competitive position in relation to conventional energy technologies and older industries that are firmly established. In addition to the technical risks associated with relatively new technologies, the emerging solar industry has to contend (together with all other industries) with today's economic conditions, including high cost of capital and fluctuating energy demand and prices, as well as uncertain Federal tax and regulatory policies--all of which serve to increase the perception of risk and to discourage investment. (pp. 85-87)

- Business and residential energy tax credits are essential to the near-term health of most of the solar industry because they stimulate private investment by balancing existing subsidies for other energy sources. These tax credits should be extended to 1990, with a gradual phasedown beginning after 1986. (pp. 89-91)

- For some technologies, such as the smaller wind machines, parabolic troughs, and systems for residential heating, the private sector is ready to begin or has already begun commercialization; for others, such as OTEC, decreases in Federal funding will result in a slowdown or termination. (wind: pp. 51-55; troughs: 38-40; buildings: 75-76 and 79-83)
- Support of basic and applied research and high-risk, potentially high-payoff technology development are important Federal roles. Such research provides information and knowledge which benefit the country as a whole, serve to establish U.S. competence in a growing, and progressively competitive world market, but is often not of sufficient benefit to any one interest to warrant private investment. (pp. 24-27, 97-99)
- Demonstration and commercialization projects requiring large capital outlays cannot be justified for Federal funding under present budgetary conditions. However, some engineering development projects may be justified in special cases where there is industry cost sharing. (pp. 88-89, 95-97)
- Results of Federal solar programs that have produced near-commercial technology, such as large wind machines, solar thermal electric technologies, and solar systems for building applications, should be transferred to industry as soon as possible. Technology transfer must be structured to allow for a gradual transition and to ensure that promising programs are not abandoned until the transfer is assured. (p. 92)
- Reductions in the Federal solar budget require consolidation and restructuring of Federal programs, including its management. (p. 93)
- Continuity in Federal actions is essential to solar R&D, as it is to all R&D. Furthermore, an expectation of continuity helps define the context essential to private sector investment decisions. Rapid changes and discontinuities in Federal policy and program direction over the last five

years have been disruptive to orderly technical progress and have caused uncertainties and unanticipated costs in the private sector. To stabilize DOE and National Laboratory planning and program execution, the Panel urges the Office of Management and Budget to support rolling 2-year appropriations by Congress for solar R&D, with carryover funding.

Specific Solar R&D Findings and Recommendations

1. Solar Related Basic Research

- Basic solar energy research provides an understanding of the physical phenomena that make new technology possible. Such research should be supported, in addition to current support by the Office of Energy Research, directly by the Assistant Secretary for Conservation and Renewable Energy, whenever research will benefit solar technology development. (p. 25)
- Basic research in photosynthesis and photochemistry is essential to solar photoconversion technology and is a highly promising area for continued DOE support. (pp. 25-27)
- Basic research in materials, with emphasis on three key programs--degradation, interfaces, and stable synthetic materials with good optical properties--should be vigorously supported. (pp. 25-27)
- Continued technical progress hinges on the availability of educated scientists and engineers, and therefore the DOE should continue to have a leading role in supporting solar research and education at universities. (p. 27)

2. Photovoltaics

- Among the solar technologies, photovoltaics represents a near-ideal candidate for DOE support under the Administration's policy of support for R&D in long-term, high-risk technologies with potential for eventual high payoff in utility, industrial, and residential applications. (pp. 31-32)

- Highest payoff is expected from advanced research and development of compound semiconductor and silicon thin film solar cells. Crystalline thin films hold most promise for high efficiency. In addition to Federal R&D for single-junction crystalline thin film cells, other promising areas include advanced multi-junction concepts and amorphous silicon. Technology development of high purity/low cost silicon material, concentrator concepts, advanced sheet formation, high efficiency single and polycrystalline silicon solar cells and module endurance is also necessary. (pp. 32-35)
- Continued DOE support is also needed for an R&D program on innovative concepts to conduct advanced research in such areas as electroytic cells, polymers and new materials with the potential for major photovoltaic breakthroughs. (pp. 35-36)
- DOE support for the 1 MWe Photovoltaics Sacramento Municipal Utility District (SMUD) demonstration project should be discontinued. It constitutes a demonstration of a technology where the current economics make large scale commercialization unrealistic. (p. 36)

3. <u>Solar Thermal</u>

- Central receiver technologies are rapidly becoming ready for transfer to industry. Only a testing program to acquire technical performance and cost data during Solar One plant operation should be Federally supported. In addition, the Department of Energy could cost share with industry on programs which will provide advanced receiver and thermal storage concepts. (pp. 35-40, 45-46)

- The Department of Energy should now emphasize parabolic dish technology development because of its potential for higher efficiencies and lower costs. Two or three small, multi-module experiments should be selected for cost-sharing. (pp. 40-41, 46-47)
- Parabolic troughs are commercially available. Only operational testing should be Federally supported. Generic R&D on materials and structures remains to be supported. (p. 39)
- DOE programs in basic and applied research related to solar thermal R&D need a much sharper focus with increased funding for advanced technology base development to support the next generation of solar thermal systems: advanced materials with good optical, thermal, and structural properties; advanced, low-cost structures, and advanced processes should be examined. (p. 48)
- The hemispherical bowl program should be discontinued, because of low average efficiency and costly thermal energy transport. (pp. 31, 47)
- The Panel remains uncertain about the prospects for solar pond technology. Monitoring and periodic evaluation are recommended. (pp. 41-42, 47)

4. <u>Wind</u>

- Continuated DOE support for data gathering, analysis, and publication of test results on the three MOD 2 machines at Goldendale, Washington, is recommended. Such operational testing should provide the technical and cost data needed to transfer this technology to industry. (pp. 50, 53-54)
- Small wind machines are commercially available. The Panel recommends Federal support for small wind demonstration projects be phased out by 1985. Federally-maintained testing facilities should be continued,

contingent upon industry use. All testing expenses for particular machines should be borne by those requesting the tests. (p. 54)

- Some advanced wind research areas such as: wind distribution, aerodynamics, structural response, predictive design tools, and advanced concepts, remain significant and require continued DOE support. (pp. 49-50)
- If there is a continuation of an overall solar budget at approximately the FY 1982 level, the Panel recommends completion of the cost-sharing MOD 5 development program, with industry funding all hardware, construction and installation. Completion of this program will provide the technical and cost data necessary to evaluate wind technology for commercial utility application. (p. 54)

5. <u>Ocean Thermal Energy Systems (OTEC)</u>

- DOE involvement in the preliminary OTEC design program should be completed; however, no further demonstrations should be Federally funded. (p. 60)
- A modest DOE technology base effort should be continued in support of private efforts. (p. 61)

6. <u>Biomass Energy</u>

- The current DOE biomass energy program requires sharper focus. A comprehensive R&D framework emphasizing biological resources and, secondarily, related conversion technologies for their use, should form the basis for implementing a program that establishes clear objectives, priorities, and responsibilities. (p. 70)
- Future achievements in biomass will most likely rest on a strong basic program in biological energy research. The basic research atmosphere

in biotechnology is, as in solar photochemistry, one of excitement and rapid change, but needs to be extended into those areas directly related to solar energy from biomass. (p. 70)

- The DOE should conduct basic research in expanding the resource base of both terrestrial and aquatic plants and secondarily in expanding the technology base in biological and thermochemical conversion of biomass, especially lignocellulosic materials from forests. (p. 68)
- The DOE should continue its lead role in resource assessment, including estimates of biomass production and feedstocks, the location and availability of unused wastes, and collection of other data. (p. 68)
- Environmental aspects of biomass are significant and require continued R&D support. (p. 69)

7. Buildings Solar Energy Research

- Research and Development leading to improved energy performance in buildings should be given higher priority.
- Current DOE programs which test the energy performance of buildings should be continued and the results documented.
- DOE should establish a comprehensive buildings solar energy research program aimed at improving the energy performance of buildings. This program should combine all DOE research and development in solar energy and conservation in buildings into one organizational unit. (p. 79)
- Major research areas that are appropriate for continued DOE R&D funding include work in materials with selective thermal, optical, and structural properties; new systems for heating and cooling; in heat and mass transfer; and in lighting in buildings. Research in these areas

promises to reduce the cost of energy in new as well as more than 80 million existing residential and commercial buildings. (pp. 73-74)

- DOE should initiate discussions leading to the establishment of an industry-supported Buildings Energy Research Institute. (p. 82)
- A special effort should be made to document DOE results in such language, and to use unit of measurement which will facilitate their use by the building trade industries.

The Panel summarized its findings and recommendations by assigning them to one of four overall priorities in Table A on Page 12.

TABLE A

OVERALL PRIORITIES	SOLAR-RELATED BASIC RESEARCH: PHOTOCHEMISTRY	SOLAR-RELATED BASIC RESEARCH: OTHER BASIC	PHOTOVOLTAIC	SOLAR THERMAL	WIND	OTEC	BIOMASS	BUILDINGS
HIGHER	o Photochemistry of H_2O; CO_2; N_2 - Visible light sensitizers - Back reactions - Electronic excitation - Redox reactions o Photosynthesis	o New materials o Degradation o Interfaces	o Single-junction crystaline thin films o High-efficiency cells o Amorphous Si o Innovative concepts R&D	o Testing performance of Solar One Receiver o Development and experimentation of 2-3 promising parabolic dish/engine modules	o MOD-2 and WTS-4 testing		o Design comprehensive R&D program, organization o Resource enhancement technologies research o Environmental impact assessment	o Performance testing and documentation o Consolidate buildings energy research program in DOE o Building thermal systems research o Materials research o Indoor air quality assessment
MEDIUM			o High-purity/low cost polysilicon o Concentrator concepts	o Testing performance of parabolic troughs o Design R&D in materials, structures and processes for next generation thermal systems o Advanced receiver and thermal storage concepts	o Continue Federal test facility contingent on industry paid use		o Conversion technology research	o Integrate in commercial building heating/cooling/daylighting o Residential cooling and dehumidification
LOWER			o Silicon sheet o Durability o Balance of systems	o Monitor Solar Pond developments	o MOD-5 cost-share program	o Preliminary design of 40MW plant o Modest R&D effort		o Heat and mass transfer research
NOT RECOMMENDED FOR FEDERAL FUNDING AT THIS TIME			o SMUD demo	o Hemispherical Bowl o Solar Pond demo o New parabolic trough or central [illegible]	o Small wind after 1985 o Large wind after MOD-5	o Demos or pilot plants		

II. INTRODUCTION

A. Background

Since 1973, the Federal Government has played the dominant role in development of solar energy technologies in the United States. The oil embargo of 1973, and subsequent price boosts, spurred national interest in solar and other renewable energy technologies. The Federal role grew substantially to include not only basic and applied R&D, but also joint participation with the private sector in demonstration plants, commercialization, and public education.

Federal funding of solar activities grew commensurately. In the early 1970s, funding for solar R&D was only a few hundred thousand dollars; by 1982, it had grown to $570 million dollars per year. Table B shows the solar R&D budget for 1979 - 1982. In addition, the Federal Government provided incentives to the solar market such as the business and residential energy tax credits and further supported solar technologies through the regulatory provisions of such legislation as the Public Utilities Regulatory Policy Act (PURPA).

With the help of this Federal support, the solar industry has made significant progress in the past 10 years. The industry's more impressive technological accomplishments include the achievement of a 300% increase in thin film photovoltaic efficiency and a five fold decrease in photovoltaic module costs, the attainment of a 26% net conversion efficiency of sunlight to electricity with a parabolic dish, Stirling engine experiment, the operation of the Central Receiver Solar One project, and the annual installation of 17 million square feet of solar hot water collectors.

TABLE B
SOLAR BUDGET HISTORY
1979 - 1982

SOLAR ENERGY R&D FUNDING
BUDGET AUTHORITY
(In Millions)

TECHNOLOGY	FISCAL YEARS 1979	1980	1981	1982	REQUEST 1983	TOTAL FY79-83
ACTIVE HEATING & COOLING	$ 73.4	$ 56.9	$ 38.4	$ 11.5	$ 0	$ 180.2
PASSIVE HEATING AND COOLING	16.3	27.9	30.2	10.6	0	85.0
SOLAR THERMAL	117.2	143.2	120.0	55.9	18.0	454.3
PHOTOVOLTAICS	120.0	150.0	133.2	74.0	27.0	504.2
WIND	59.6	60.6	54.2	34.4	5.5	214.3
OCEAN THERMAL	41.1	43.0	34.6	20.8	0	139.5
BIOMASS	42.4	33.0	27.2	20.5	6.6	129.7
ALCOHOL FUELS	0	22.0	18.0	10.0	2.9	52.9
OTHER	44.2	34.6	27.0	30.5	12.1	148.4
TOTAL	$514.2	$571.2	$482.6	$268.2	$72.1	$1,908.5

While a growing solar energy industry exists, estimates of the eventual contribution of solar technologies to United States energy supplies vary widely. Realistic estimates suggest a 5-11% solar contribution, excluding hydro. Hydroelectric power generation has been commercially available for many years, contributing a significant fraction of total electricity production in a number of regions. Conventional technologies of biomass conversion, primarily wood burning, currently supply about two percent of U.S. energy needs. In addition to these, several other solar technologies are becoming increasingly available in the marketplace.

Since 1981, the Administration has redefined the Federal role in energy R&D and reduced Federal funding for solar R&D--particularly for costly demonstration and commercialization programs. In general, the demonstration and commercialization phases in the process of bringing new technologies to market are to be left solely to the private sector. The Administration's overall energy program, as described in the 1981 National Energy Policy Plan, is to:

a) Eliminate large Federal subsidies for conventional fuels

b) Continue for the time being existing tax credits to stimulate investment

c) Focus Federal R&D on long-range, high-risk, potentially high-payoff projects.

Congress and others have shown concern about the private sector's financial incentive or technical ability to fill the void created by Federal budget cuts in solar programs and about the consequences of the transition to reduced funding levels called for by this new policy. There is a particular concern that the results of past Federal R&D, demonstration, and commercialization efforts will be lost.

Representative Don Fuqua, Chairman of the House Committee on Science and Technology, expressed these and other concerns in a letter to Department of Energy Deputy Secretary, W. Kenneth Davis on December 10, 1981 (Appendix C). Representative Fuqua suggested that the Energy Research Advisory Board (ERAB) be asked to conduct a study of solar R&D to examine these issues.

Deputy Secretary Davis agreed that "a more definitive examination of the appropriate Federal role in solar R&D is needed", and, in a letter dated March 16, 1982, to Mr. Louis Roddis, Chairman of ERAB, requested that a Panel be formed to address these concerns (Appendix D). Specifically, the Board was asked to "undertake a study of the solar energy programs that would help the Department define the most effective Federal program given the limited resources that will be available....This analysis should help ensure that future Federal investments will provide the long-term scientific base needed for a healthy and competitive national effort."

In response, Mr. Roddis convened a Solar R&D Panel comprised of persons from industry, academia and state government. The Panel availed itself of selected technical literature, special staff studies (listed in Appendix F), and met with over 70 solar energy experts on five separate occasions in order to ensure that a broad range of expertise and perspectives were considered. This report reflects the Panel's extensive deliberations on the issues before it and subsequent review by the Energy Research Advisory Board (ERAB). Appendix A identifies the members of the Solar Panel. Appendix E contains the names of participants and the agendas of the Solar Panel meetings. Appendix B lists the members of ERAB.

B. Purpose and Scope of the Report

Deputy Secretary Davis' letter of March 16, 1982, serves as the basis of this report. It requests the Solar Panel to define the appropriate Federal role in solar energy development and to identify for Federal support long-term, high-risk, potentially high-payoff R&D and technology transfer activities. Summarized below are the specific questions the Panel addressed for each solar technology:

1. In each solar technology, what specific research objectives should be supported by the Federal Government?

2. What is the present ability and incentive of industry to assume leadership for continued solar development?

3. What mechanisms may be needed to ensure an efficient transfer of solar technology developed by government to the private sector?

4. What is the appropriate Federal role with respect to each solar technology?

The following chapters of this report attempt to answer these questions. Chapters III through IX examine each of seven areas of solar technology: solar related basic research, photovoltaics, solar thermal, wind, ocean thermal energy converstion (OTEC), biomass and buildings solar energy research. Hydroelectricity was omitted because the Panel saw no need for Federal R&D in this mature technology provided by an established industry. Chapter X examines industry-related issues common to many or all solar technologies. Chapter XI presents the Panel's detailed findings and recommendations.

C. Methodology and Approach

The Reagan Administration's energy R&D policy focuses Federal support on long-term, high-risk, potentially high-payoff R&D and technology transfer to the private sector. In this context, the appropriate Federal role in solar energy development depends in part on an assessment of the ability of the solar industry to undertake additional R&D and the effectiveness of measures to obtain a satisfactory return on past public investment. The definition of that role is complicated by the diversity of the solar industry and its place in the nation's energy market.

The solar industry not only contributes to, but is affected by, the national economy as well as energy markets. Present financial conditions, particularly high interest rates, and recent fluctuations in energy demand and prices will directly affect private investment in the solar industry. Federal action, including changes in regulatory and tax policy and in R&D programs funding, will also have direct impact on the health of the solar industry. For these reasons, the Solar R&D Panel took a pragmatic approach to assessing Federal solar R&D and technology transfer activities.

The Panel conducted a detailed review of a wide range of technology specific options based on the state of each technology, industry and market conditions, and the transferability of each technology from the Federal Government to the private sector. The Panel evaluated each option on its merits and suggested an appropriate Federal role only in those with substantial promise. Many options were discarded; the rest were broadly ranked because the status of the technologies and the link between Government and industry are so different in each case.

In conducting its review, the Solar Panel was assisted by other recent ERAB reports. In November 1981, ERAB prepared a report on Federal Energy R&D Priorities, which included recommendations on FY 1982 funding for solar programs. Also, in November 1981, ERAB completed a report on Biomass Energy, which reviewed all aspects of biomass, especially its potential in U.S. energy supply, and made research recommendations. An ERAB report on conservation R&D, now in progress, will be relevant to some solar energy areas. In addition, the Solar Photovoltaic Energy Advisory Committee (SPEAC), established under the Solar Photovolatic Energy R&D Act of 1978, submitted its report to ERAB and the Secretary of Energy in October 1981. That report discusses the status of photovoltaic research and key R&D issues.

III. SOLAR-RELATED BASIC RESEARCH

A. Critical R&D Issues

The use of solar energy is made possible by our understanding of some of the basic physical phenomena which govern the conversion of solar energy to useful purposes. Basic research in these phenomena provides the understanding necessary for technology development as well as the education of scientists and engineers necessary for transferring this knowledge for widespread commercialization. This chapter considers some aspects of solar-related basic research with emphasis on photochemistry.

1. Photochemistry Research

Plant photosynthesis is a natural energy conversion and storage system which reduces 400 billion tons of carbon dioxide world-wide to energy rich carbon compounds annually. There is insufficient knowledge today to chart a straight path to a large scale energy technology based on photochemistry, but the fact that photosynthesis works for natural and agricultural purposes shows the possibilities for the future of such a technology. A better understanding of the basic principles of photochemistry may allow the direct conversion of vast resources of water and carbon dioxide to useful fuels with solar energy, as well as improve the technology for converting that energy to electricity.

Four points summarize the attractiveness of solar photochemistry:

a. The potential to convert water, an available resource, to a useful fuel, hydrogen, which is both clean and storable.

b. The generation of fuel by electron excitation with a theoretical efficiency of 30%, which significantly exceeds the summertime efficiency of 1% attainable by natural photosynthesis.

c. The continued need for chemical fuels, which could be met by photochemistry technologies and developed by an existing chemical industry.

d. The potential of photochemically generated fuels to avoid environmental degradation associated with fossil fuels such as the "greenhouse effect" of CO_2 build-up, and acid rain.

An infinite number of sunlight-induced, fuel-forming reactions can be written. Three conversion reactions may focus the discussion:

$$2H_2O \xrightarrow{\text{sunlight}} 2H_2 + O_2$$

$$2H_2O + CO_2 \xrightarrow{\text{sunlight}} \underset{\text{(methane)}}{CH_4} + 2O_2$$

$$3H_2O + 2CO_2 \xrightarrow{\text{sunlight}} \underset{\text{(ethanol)}}{C_2H_5OH} + 3O_2$$

In each of these examples, the reverse reaction could be a combustion process to liberate heat from stored solar energy in the energy rich compounds and regenerate the original raw materials.

There are a large number of photochemical reactions, and our understanding of them varies. Nevertheless, generic research in three major areas will improve our understanding in specific ways that will tend to provide the basis for the development of photochemistry-based technologies.

The critical basic research issues in photochemistry are those associated with improving solar response, controlling the reverse, or back, reaction of energetic photoproducts, and affecting mechanisms that employ two or more light quanta per fuel molecule.

a. Solar Response--Generally, because water and carbon dioxide are transparent, they must be sensitized to the solar spectrum; the sensitizer must absorb the solar energy and channel it into the desired chemical process. All of the inexpensive, abundant starting materials for fuel production are conspicuously transparent to the solar spectrum. The key materials H_2 and CO_2 are both visibly transparent (colorless where the solar energy is greatest) and yet natural plant systems effect the reduction of CO_2 to carbohydrates with solar energy. In the natural system, chlorophyll, which gives green plants their color, is actually the solar absorber, and this photoexcitable substance transduces the optical energy to stored chemical energy by initiating a series of electron transfer events.

b. Back Reaction-- The aim of solar production of fuels is to produce a mixture that is thermodynamically unstable (e.g., combustible). For useful fuels, the objective is to be able to isolate and store the products, despite the thermodynamic tendency to revert to the raw materials. Building in kinetic barriers to back reaction is therefore crucial to being able to efficiently accumulate fuels from sunlight.

c. Multi-Photon Reactions-- Photochemical processes like those involving H_2O or H_2 and CO_2 for fuel production from solar energy seemingly require many elementary steps. Solar processes that begin with the excitation of electrons will likely require sensitizer systems that can efficiently use at least two photons (light quanta) per fuel molecule in order to realize a good overall solar efficiency.

2. Other Basic Research Needs

In addition to photochemistry, three generic areas of solar related basic research have been identified as areas of outstanding potential for improving the performance and reducing the cost of solar conversion technologies:

a. Degradation-- Economically viable systems must be durable. All practical solar systems involve the use of materials that can and often do undergo undesirable change. Corrosion in OTEC, materials fatigue in wind systems, photodegradation of exposed plastics, and destruction of reflecting surfaces are only a few examples of these problems.

b. Interfaces-- Interfaces play a key role in systems as diverse as solar hot water panels and natural photosynthesis. Interfaces are especially crucial to those systems which depend on the primary excitation of electrons by sunlight such as photovoltaic cells and solar photochemistry. Yet the structures of interfaces and their synthesis are not well understood. Understanding interfaces could lead to genuine breakthroughs in photovoltaic devices in terms of improved efficiency, longer lifetime, and lower cost.

c. Synthetic Materials-- Solar energy is a diffuse resource. The realization of a significant contribution to our energy supply from solar will require large amounts of durable, lightweight and inexpensive materials to collect and convert incident solar radiation. New synthetic materials have the potential for improving the cost, durability, and efficiency of solar apparatus.

B. Status of Solar Photochemistry and Basic Research

The Department of Energy, through the Office of Basic Energy Sciences, is a large supporter of basic research with applicability to solar technologies. Its funding supports research activities at major national laboratories such as Brookhaven, Argonne, the Solar Energy Research Institute, Sandia, and Lawrence Berkeley as well as at a large number of universities. Federal agencies other than the Department of Energy also support some basic research related to solar technologies. The scientific work supported by Defense, Agriculture, NASA, and NSF contributes to the base of scientific knowledge on solar energy, but these programs do not constitute large efforts specifically directed toward the fundamental understanding required to develop a large scale solar technology.

Private industry is supporting programs in photoelectrochemistry. There are significant programs at Bell Laboratories, Standard Oil of Indiana, Standard Oil of Ohio, Phillips Petroleum, the Allied Corporation, and Texas Instruments to name a few. A few new companies formed to conduct biological energy research have just begun work in this field. Industry also funds materials research but generally for reasons unrelated to an interest in solar energy.

In the area of fuel production, solar assisted electrolysis of H_2O to form H_2 has been accomplished with 12% solar efficiency. In 1972, the efficiencies in such systems were less than 1%. Nonetheless, present efficiencies fall short of theoretically predicated values. Thus, while good progress in solar fuel production has taken place in the last decade, much remains to be learned about factors that limit solar energy conversion efficiency in experimental systems and about ways to overcome them.

The emergence of the biological sciences has not, as yet, made a large impact on any solar technology. In the time since the Division of Biological Energy Research was formed in 1979, there has not been sufficient time to realize major advances in this area. Biotechnology does not really yet exist as a commercially profitable industry, but the field has captured significant talent and resources. The basic research atmosphere is, as in solar photochemistry, one of excitment and rapid change, but this enthusiasm has not yet extended to those areas directly related to solar energy. However, future achievements in biomass will likely hinge on a strong basic program in biological energy research.

C. Transfer of Federal Research Information

There have been no intrinsic barriers to the flow of information from basic research supported by the Federal Government. Through traditional channels such as scientific meetings, scholarly publications, and public lectures, rapid dissemination of new results takes place among researchers. However, the development of closer university-industry relations and the move by the Federal Government to restrict transfer of information to certain foreign countries may alter this openness to the detriment of communication within the scientific community. For proprietary reasons, the flow of results from industry even in basic research is often restricted.

Personnel rotation and exchange programs, with sabbaticals and residency arrangements between universities, national laboratories and research centers, and industry would improve research and technology transfer considerably.

D. Recommended Federal and Private Sector Roles and Objectives

Basic research is generally ideas limited. As such, there are no major institutional limitations to who can or should carry out basic research. Both Government and some industries have conducted basic research in the past, and continue to do so. Nonetheless, universities traditionally have been responsible for conducting a substantial fraction of the basic research activities, especially in photochemistry.

The Federal Government has provided most of the financial support for this research. The private sector has provided some financial resources and advanced industries have conducted some basic research.

Because research is knowledge oriented (as contrasted to a program, or objective, or technology orientation), it remains the Federal role to provide the resources necessary to support it. It is the Government's responsibility to ensure the continuity in program support necessary to attract the quality researchers and to conduct research programs that will assure progress.

The Basic Energy Sciences (BES) Office has sponsored these activities in the past and should continue to do so. As the Federal role changes to support more of the basic and applied sciences portion of the technology innovation process, it is appropriate that larger portions of the Assistant Secretary for Conservation and Renewable Energy (AS/CE) budget be allocated to basic and applied research, especially when these activities are clearly associated with the development of basic knowledge applicable to given solar technologies. At the same time, management practices for AS/CE funds for basic and applied research should more closely resemble those of the Basic Energy Sciences program.

The following basic research areas are important to achieve the knowledge base necessary for a solar photochemistry technology and to support large scale energy systems:

-- Visible light responsive sensitizers for fuel generation

-- Synthesis and characterization of photosensitive interfaces

-- Synthesis of uniform areas of photoactive materials

-- Structural and chemical probes of interfaces, old and new

-- Photochemistry of CO_2, H_2O, and N_2 at interfaces (Emphasis on interfaces is justified because all large-scale photochemical systems employ interfaces including photography, xerography, and natural photosynthesis. Additionally, recent advances in instrumentation to study interfaces have been remarkable, suggesting that more intense study will yield breakthroughs.)

-- Photosynthesis (mechanisms, understanding, and structural aspects)

-- Electronic energy transfer following photoexcitation

-- Electron transfer catalysis

-- Synthesis of catalysts for the redox reactions

-- Mechanisms for kinetic inhibition of back reaction of energetic substances, especially the redox intermediates

-- Photodegradation mechanisms of solid materials and chemicals

-- Efficiency limiting factors, including thermodynamic limitations.

Basic research for the development of a technology base on natural photosynthetic systems includes:

-- Continued development of understanding of the primary processes of photoelectron transfer in natural photosynthesis

-- More knowledge about the last steps in catalysis in H_2, O_2, and CH_4 production

-- A full understanding of the biosynthetic route to hydrocarbons--particularly isoprenoids

-- An understanding of the generic controls of

a) the efficiency of photosynthesis

b) the ultimate products of photosynthesis--particularly the desired hydrocarbon fuels

-- Continued efforts to activate such genes in microorganisms (cyanobacteria) as well as in higher plants.

Basic research in materials, with emphasis on the three generic problems of degradation, interfaces, and synthetic materials with unique properties, is required to develop the solar industry in each sector.

The final recommendation concerns education and training of personnel in the solar technologies. Basic research in universities ensures a steady flow of talent in this emerging technology. Advances in long-term, high-risk, potentially high-payoff areas such as photovoltaics and solar photochem-istry depend exclusively on the scientists and engineers who will direct their talents to solar technologies. These people must have the full advantage of a strong education in the related scientific and engineering disciplines. The Federal Government should continue to take the lead in the support of basic research and education in solar related areas at universities.

IV. PHOTOVOLTAICS

A. Critical R&D Issues

Photovoltaics (PV) have the potential to make a significant contribution to our national energy requirements in the long term, provided that costs can continue to be reduced. By converting sunlight directly to electricity, PV could be used to meet electricity needs in buildings, industry, and to generate electricity at utilities. Among the solar technologies, photovoltaics represents a nearly ideal candidate for DOE support under the Administration's policy of support for research and development in long-term, high-risk technologies with the potential for high payoff. To become commercially viable on a large scale, photovoltaics must achieve an overall cost reduction of a factor of ten, a concurrent improvement of efficiency of a factor of two, and be three times as durable. Currently, the photovoltaics industry is based principally upon single crystal silicon in various sheet forms. This industry is addressing existing specialized small markets with a relatively high-cost product. The feasibility of extrapolating this technology to cost levels sufficiently low to be of significance to utilities must yet be demonstrated. A number of other photovoltaic technology options, based principally upon thin films and offering significant cost reductions, also have been under consideration. So far, low efficiencies and lack of stability have limited their application.

The DOE photovoltaic program has been well managed, as demonstrated by progress in recent years. In good part, the critical R&D issues addressed here take into account the analyses of photovoltaic program managers assuming continued reduced levels of DOE participation.

Low cost must be achieved for photovoltaics to have a significant energy impact. The most direct path to low cost is through high efficiency because of associated balance-of-systems cost. A recent analysis of the performance needed to make photovoltaics competitive with other means of electric power generation indicates that overall flat-plate module efficiencies should reach roughly 15% for widespread use. Other uses may be less demanding, but similar analyses for other applications were not made available to the Panel. Currently, single crystal silicon modules are typically 8% efficient, and are expensive. Thin film modules, although offering the potential for low cost, are only in limited production and are generally in the range of 4% - 6% efficient. (It should be noted that PV efficiency is typically an inverse function of the area involved. Thus, cell efficiencies are typically higher than module efficiencies.)

Presently, three approaches show promise for achieving high efficiency at low cost. The first is to concentrate on the improvement of cell efficiency of single-crystal silicon in its various sheet forms, such as Czochralski (Cz) wafers, ribbons, and large grain cast material; this approach offers significant promise since it is founded upon a broad technology base. The second is to pursue thin-film and amorphous silicon research, which has the potential for leapfrogging present technology; Silicon (Si), Gallium Arsenide (GaAs), Cadmium Sulfide/ Cuprum, Indium, Selenide (CdS/$CuInSe_2$, and Cadmium Teluride (CdTe), are some of the most promising thin film materials. A third promising approach is compound semiconductor, multi-junction cell technologies.

B. State of the Industry

In a commercial sense, today's industry is small, has little profitability and therefore, is fragile. However, considerable private resources have been invested in photovoltaics, primarily by the oil industry. Currently, at least eight major oil companies are investing in photovoltaics research.

The Federal Government has played a major role in identifying the technology options upon which both today's industry and investment are based. In many cases, initial entry into photovoltaics by the oil industry came from acquisition of or association with smaller firms whose technology was nurtured by Federal R&D. Examples are Mobil-Tyco, ARCO/Solar Electric International, and Exxon/Solar Power. In some cases, the Federal Government provided technology evaluations, in others, a market for early product introduction.

In addition to these major PV industries, a number of smaller activities have been encouraged by DOE support. These range from processing equipment such as crystal pullers and ion implanters to silicon material processing sequences--all important in today's industry.

With the entry of major energy corporations into photovoltaics, much of the initial role of Government has been taken over. These corporations feel confident that they can now carry the technology forward, especially single crystal silicon technology.

The position of other corporations that have participated in the DOE program, especially small-and medium-sized businesses, is less certain. Because of large company involvement, the long-term payoff of these energy technologies, and limited capital, it is unlikely that private investment will sustain these operations. This industry infrastructure may not survive proposed DOE cutbacks. Nonetheless, this infrastructure is valuable because diversity in the PV industry holds out the promise of valuable innovations in PV, many of which have come from the smaller companies. The existing industry infrastructure is also necessary for a continuing source of technical innovation, providing important components and products to the major PV suppliers, and responding rapidly to the market.

Because its modular nature is conducive to remote small-scale use, PV offers near-term commercialization both domestically and internationally. However, stiff competition on the international front is now arising from the Japanese and European governments. An aggressive, multi-pronged approach involving many corporations would be the best strategy to capture this market. Japan is rapidly becoming a strong competitor in this relatively new industry. Japan is already competing in the Cz wafer and ribbon silicon module market. While pursuing a number of research avenues, it has established a strong program emphasis with a long-term commitment to amorphous silicon. It is apparent that this program is aimed at mass production of cells for consumer products. These mass production techniques may open up possibilities for overall cost reductions which give them an advantage in the worldwide PV energy market.

C. Transfer of Federal R&D

So far, Federal R&D related to advanced technology has been transferred with reasonable efficiency, primarily by technical interchange meetings, large company acquisition of small entities, and fluidity of technical personnel both within the industry and between government and industry. However, with reduced Federal support, demonstration programs underway may not be adequately monitored to acquire valuable performance data.

D. Recommended Federal and Private Sector Roles and Objectives

Generally, continued DOE funding for research is needed until industry assumes responsbility for further development or until the technology concept proves either technically or economically unfeasible. Cost goals for the PV program measuring economic feasibility should be set using standardized cost analysis. However, the achievement of these goals should not be fixed to specific dates or time frames because it is not practical for this rapidly changing technology. Cost goals and evaluation methods are needed because only with such guidelines can resources be focused on the most promising approaches.

Specific R&D funding recommendations follow in order of their priority:

1. Single-Junction Crystalline Thin Film Cells

These films have potentially the highest efficiency and lowest cost. In particular, thin single crystal and polycrystalline silicon and gallium arsenide should be pursued. In addition, other thin films such as $CdS/CuInSe_2$ and CdTe should be investigated. Techniques for deposition, grain nucleation, grain growth, and recrystallization must be addressed. Low cost substrates must be part of this evaluation. Approaches to high efficiency cell fabrication involving grain boundary passivation and multi-junctions should be considered.

2. Advanced High-Efficiency Cell Concepts

Processes should be developed to achieve high conversion efficiency (20%) single-crystal silicon, large-grain polycrystalline silicon, and thin-film solar cells. The materials to be considered are Cz wafers, ribbons and polycrystalline ingots, sliced sheet, and thin films. Although the industry fabricates many lower efficiency cells from these materials now, research into advanced processes in both single- and multi-junction cells is needed to achieve dramatic increases in efficiency. This research area warrants DOE support.

In addition, as part of the DOE program to produce cost savings, the development of processing techniques that involve the integration of individual process steps should be pursued. Examples would involve combining material purification and deposition, deposition and sheet growth, and metalization, anti-reflective coating, and encapsulation. During this research, consideration must be given to the resulting stability of the solar cell system and the potential for scale-up of the manufacturing processes.

The DOE program should support development of advanced processing equipment when it is necessary to implement a promising process step or process sequence as part of a Federally funded research program. Process equipment support can be considered when questions of process scale are critical.

3. Amorphous Silicon Solar Cells

Because of widespread activity, both nationally and internationally, in the development of amorphous silicon solar cells, only basic research to assist industrial activities should be pursued.

Research should be conducted to understand the basic mechanisms of cell performance, such as the role of hydrogen and cell stability. In addition, the research should examine the scale-up potential of various fabrication processes. Both single-junction and multi-junction devices should be investigated.

The size of the amorphous silicon program should be sufficient to induce the major participants to attend program review meetings, and thereby help cross-fertilize and guide internal industrial research.

4. Innovative Concepts Program

Although innovation is the cornerstone of the entire research program, a specific innovative concepts program similar to that previously initiated by

DOE is recommended. This program can be used to open up PV research to advanced thinking on electrolytic cells, polymers and new materials that have the potential for major breakthroughs. This program should be open to competition from universities, industry, and others. Cost sharing, dependent upon participant size, should be encouraged. Additional cost sharing for expansion of encouraging approaches in subsequent fiscal cycles should also be required. This "seeding" approach would be an expeditious way to transfer technology to industry. Small companies which could not afford increasing cost sharing would have to find larger corporate partners.

5. High Purity/Low Cost Silicon Material

The cost of polysilicon dominates single crystal silicon manufacturing costs. Cost reduction is critical to the widespread use of single crystal silicon modules. The cost is dominated by the energy required to decompose the silicon-carrying gas and to deposit silicon in a usable form. This is a critical R&D issue which warrants focused effort. In particular, gas decomposition using fluidized bed reactor, advanced Siemens electrorefining and plasma assisted decomposition techniques should be investigated.

6. Concentrator System R&D

Concentrator system R&D activities are regarded by industry as high-risk and involve technology transfers from the DOE solar thermal programs. As a result, industry investment has been low in this area. However, the progress toward showing that concentrator systems are potentially low in cost is encouraging. Concentrator collector, receiver, and solar cell research should continue toward demonstration of utility of this approach in specific goal oriented programs. These should involve high efficiency solar cell development for cost reductions and system reliability improvement through advanced collector and encapsulation schemes.

7. Advanced Silicon Sheet (Ribbon Techniques)

There are now more than nine types of silicon ribbon growth processes. they have the potential to reduce cost by eliminating ingot casting and wafer slicing. In general, they suffer from breakage and residual stress, which affects solar cell performance and cell manufacturing yield. R&D should be directed toward a generic understanding of ribbon growth and toward reducing stress in silicon ribbons.

Because high efficiency is the most direct route to low cost, R&D efforts on fundamental limitations of efficiency specific to polycrystalline ribbon silicon are necessary. Processing steps and sequences which allow these limitations to be removed must also be investigated.

8. Flat Plate Module Durability

The DOE should support advanced high efficiency crystalline and thin-film module development to the extent necessary to demonstrate the technical feasibility of the various cell concepts in module form. The assembly of such modules into arrays is better left to industry.

Critical to low cost durable modules is the achievement of a twenty-year life-time. Research on module durability that addresses encapsulation materials, module failure mechanisms, and accelerated life testing is warranted.

9. System Experiments

Some system experiments or tests are necessary to resolve important technical issues, such as optimum field voltage, design, and array field output degradation. These minimum-sized experiments should be distinguished from demonstration projects, the objectives of which are to demonstrate a production capacity at commercial scale and cost. Demonstration projects are in the sphere of industry. The money used to cost share the Sacramento Municipal Utility District (SMUD) project, for example, would be better spent on other research programs.

The Panel recognizes the importance of balance-of-systems (BOS) cost reductions. BOS includes PV module support structures, power conditioning and energy storage. Currently, BOS costs are an important part of PV system costs, in some cases 50 percent of the total initial cost. As module costs are reduced, BOS costs could dominate the PV system costs. However, BOS cost reductions are not believed to be in the realm of advanced high-risk R&D, but are engineering development areas. When PV module costs are reduced, industry will take the necessary engineering steps to also reduce BOS costs. EPRI has targeted BOS costs as a central aspect of its PV R&D agenda and has already conducted valuable research.

10. Demonstration Projects

Currently, DOE is funding a 1 MWe PV demonstration plant to be built by cost sharing with the California Energy Commission and the Sacramento Municipal Utility District (SMUD). A privately funded 1 MWe PV demonstration is scheduled to begin operation in late 1982, and others are contemplated. Consistent with an overall Administration policy of leaving demonstration plant construction to the private sector, the Panel recommends the termination of further DOE funding for the SMUD project.

Summary of Federal and Private Roles

In summary, the DOE should continue to support high-risk research, and to nurture both the breakthrough and evolutionary approaches to achieving high efficiency, low cost photovoltaics for national energy impact. Both areas of research should be continued in order to maintain an efficient use of DOE resources and industry investment.

Industry has had in the past and currently has a major role both in the research and development of some photovoltaic cells and in the production of cells and systems for commercial sales. The complementarity of DOE/industry involvement has been satisfactory and fruitful and should continue.

V. SOLAR THERMAL

A. Critical R&D Issues

1. Introduction

Solar thermal energy systems convert the sun's radiant energy to heat energy. The heat may then be used directly for industrial applications or to generate electricity. A unique feature of the solar resource is the ability to use radiant energy to produce high temperatures. Temperatures up to 1370°C can be achieved. To date, a 20% net conversion efficiency of sunlight in to electricity out has been achieved at the Solar One Central Receiver Plant. A net efficiency of 26% has been attained with a Parabolic Dish/Stirling Engine system.

Solar thermal covers five different technologies. These exhibit varying degrees of technical maturity and acceptance in the marketplace. With the exception of solar ponds, the solar thermal technologies concentrate solar energy to various degrees, sufficient to achieve higher efficiencies for the production of industrial process heat, electricity, and fuels.

2. Parabolic Troughs

Parabolic troughs are the solar thermal technology with which there has been the most experience. A number of systems are in operation. More than three-quarters of a million square feet of collectors have been installed as a result of field test experiments, research and development projects, and commercial sales. In successive projects, parabolic trough systems have demonstrated increasingly higher efficiencies, higher reliability and lower costs.

3. Central Receivers

Solar thermal central receiver technology is a near-commercial solar energy option for electric power production for utility systems. If the current momentum in this technology can be maintained, commercial application of central receivers can begin during the next few years. However, it is at this point--the demonstration stage--that some specific government involvement is most critical to ensure a successful transfer of technology to the risk-adverse utility industry.

The best evidence of the status of development of solar central receiver technology is seen at the 10 MW "Solar One" pilot plant near Barstow, California. Operation began on April 12, 1982, with initial power production to the Southern California Edison electric grid. After a three to four month start-up period, a five-year test program will begin this year. The first two years of operation will include experimental testing of the major subsystems and evaluation of operation, maintenance requirements and costs. This period will be followed by power production tests to obtain longer term operation, maintenance, reliability, and cost data.

In addition to Solar One, five other similar, but smaller (1/2 to 2MW), government sponsored central receiver pilot plants are starting up in Western Europe (Spain, France and Italy) and Japan. These pilot projects serve as laboratory facilities to provide information and firsthand experience with the operation and maintenance of this new technology. Various industrial concerns are currently considering even larger installations. Utilities and equipment manufacturers are watching and monitoring progress to more accurately assess performance and cost for the next installation, perhaps in the 30-100 MW range.

Extensive component testing has also occurred in the U.S. in recent years. Four different receiver concepts using different heat transfer fluids--air, water, salt, and sodium (the latter at private expense)--have been tested and show encouraging results. Also, four complete second generation heliostat systems have been tested.

Results from these prototype tests and studies have demonstrated that commercial scale production of sun-tracking heliostats is feasible and can be economically attractive in large quantity production. There appears to be no insurmountable technical barrier to the successful development of central receiver systems.

4. Parabolic Dishes

Parabolic dish concentrators provide two-axis tracking of the sun for high collector efficiency coupled with highly efficient heat engines. Each concentrator/engine unit or module can independently produce thermal and electrical energy. This technology represents a particularly promising technology for a diverse market ranging from small isolated loads to multi-megawatt grid-connected systems. Recent tests using Stirling and organic Rankine engines established technical feasibility and sunlight conversion efficiencies in excess of 26%. The modularity of these 20 to 25 KWe units, as well as a short lead time for construction, provide favorable flexibility in load planning and financing of new electric generating capacity.

The technology is new. Considerable generic research remains to be done, particularly in the areas of reflective and ceramic materials, non-gaseous fueled hybrid receivers to increase capacity factors, system level controls, and alternative concentrator design. Small, multi-unit prototype projects will be required to develop proof that parabolic dish systems for electricity production can interact on an autonomous basis. The cost of such a program is relatively small and cost sharing should be encouraged.

5. Hemispherical Bowls

A 65-foot hemispherical bowl is operating in Crosbyton, Texas, and there is interest in expanding the concept to one or ten 200-meter hemispherical bowls to operate in conjunction with a new fossil fuel power plant. Cost for the power plant and one hemispherical bowl is estimated to be $10.6 million. The cost for the power plant and ten bowls is between $28 and $31 million. The remaining critical R&D issue primarily lies with low annual collection efficiency, high thermal losses, and the scaling up of the prototype design to 200 meters. However, the Panel is concerned about the comparatively low average annual collection efficiency of this technology, the thermal losses associated with the long piping of the collected thermal energy and the appropriateness of DOE funding all or part of the cost for the fossil fuel portion of the proposed demonstration plant.

6. Solar Ponds

Solar pond technology for both heat and electricity production is still in the developmental stage. It holds some promise for commercial use in those regions of the nation where huge amounts of saline water and flat, open terrain are readily available. This technology is currently being demonstrated in a two-acre pond at Ein-Bokek in Israel, generating 150 KW of electricity. The construction of a 10-acre, 5 MW pond at the Dead Sea in Israel is 60% complete, and the pond is scheduled to be in operation in 1983.

Development of the solar pond technology in the United States is confined to laboratory tests and feasibility studies. With support from the Department of Energy, Southern California Edison and the California Energy Commission conducted a 5 MW Salton Sea feasibility study. The Jet Propulsion Laboratory and the Army Corps of Engineers have also conducted tests on pond characteristics. A number of major site-related pond technology questions, such as maintenance of water clarity, local brine production, permeability of pond bottoms, questions relating to wind suppresion, and salt gradient stability, maintenance of the salinity and thermal stratification, and environmental protection remain to be resolved. On the conversion-plant technological front, brine removal and return, brine nozzles, heat exchanger and efficiency improvements remain to be resolved. On a site specific basis, solar ponds may offer a productive use of brines generated from desalinization plants.

To supplement Israeli experience, to address site specific characteristics and to evaluate different environmental and operating requirements, the Panel has considered the importance and feasibility of the United States developing its own technical base for this application. The progress of solar salt pond technology, from a few megawatt proof-of-concept pilot plant to full fledged commercial plants of tens-to-hundreds of megawatts would require successful experimental plant tests in perhaps two locations. At the same time, site specific pond-related studies and tests at various resource locations would have to be done to be followed by commercial installations based on experience and data.

7. <u>Fuels Production Using Solar Thermal Technologies</u>

Finally, there is the technical possibility of using solar thermal processes to derive fuels and chemicals. Solar thermal energy systems can be used to produce, efficiently and economically, a variety of fuels and chemicals--

including hydrogen. Solar is capable of driving high temperature (greater than 2000°F), thermo-chemical reactions, high flux (greater than 1MWe/M), non equilibrium reactions and direct photon driven processes. Solar thermal systems can provide a combination of temperature and flux not achievable through conventional process design, which can significantly enhance efficiency and result in higher value products.

8. Technology Base R&D

A number of critical R&D areas have promise for providing the technology base necessary for the next generation of solar thermal technologies including improved central receiver, dish and trough systems, with considerably improved performance and reduced energy costs. These include:

-- The development of new materials with good optical qualities and long life

-- The development of lightweight, low cost concentrating structures

-- The development of high temperature materials

-- Research into the use of thermal processes for fuels production which should be coordinated with similar activities in the biomass energy area.

Environmental issues related to solar collectors include land use (6-8 acres per megawatt for central receivers and parabolic dishes), esthetics in some cases, and, in a few cases, bird and insect mortality.

B. State of the Industry

There is a diverse cross section of American industry in solar thermal technologies, ranging from the small high technology firms to the large aerospace and petroleum companies. Fifty-seven companies represent the nucleus of the industry. The majority of larger firms are engaged in central receiver technology. The larger companies can be characterized generally as risk averse, while the smaller companies have limited economic strength.

Most of these companies are seeking sales of their first generation hardware by capitalizing on the Federal and State energy tax credits to help obtain financing; many depend upon venture capital. Two recent announcements by the parabolic trough industry of purchase power agreements with Southern California Edison (SCE) provide an indication that these systems may be on the verge of becoming commercial. However, recent market uncertainties and general economic conditions may hinder commercialization of this technology at this time. The central receiver industry is bidding on both the design phase of a DOE Program Opportunity Notice and a Notice of Program Interest from SCE that will provide the detailed design effort and market pull for near-term implementation.

In summary, the parabolic dish, hemispherical bowl and salt ponds are not yet ready for first generation commercial sales.

C. Transfer of Federal R&D

The DOE Solar Thermal Program has had close and continuing coordination with the developing industries in each of the technology areas. Approximately 75% of its R&D funds were spent through industry and, thereby, ensured an early development of personnel, expertise, and hardware transfer. DOE test facilities are used by industry for trough testing. The program has held annual technical review meetings and many topical symposia and workshops.

A number of factors inhibit rapid industrial investment in solar thermal technologies which otherwise are rapidly nearing commercial status. These include: a difficult investment climate and high interest rates, the added risk of a new technology without a long record of performance, and a complicated regulatory framework. To these inhibitors is added the uncertainty about the continuation of the Federal energy tax credits. These points are discussed in detail in Chapter X as common problems for many emerging solar technologies.

D. Recommended Federal and Private Sector Roles and Objectives

1. Parabolic Troughs

The parabolic trough technology is commercially available and requires only a low order of continued DOE support in materials research (including environmental testing) and operational testing of key demonstration projects to complete the technology transfer process.

There appears to be a minimal role for DOE after the completion of the FY 82 funded Modular Industrial Solar Retrofit (MISR) design and testing effort. Thereafter, the R&D critical issues are directly associated with the generic need for low cost, long life reflective surfaces, and receiver materials of high absorbtance and long life. Operation of a select number of DOE sponsored demonstration projects should be continued for gathering data to resolve these R&D issues and transfer of the technology to industry.

2. Central Receivers

The paramount requirement of the Federal solar thermal central receiver program over the coming years is to ensure that the Solar One experiment is carried through to a logical and thoroughly understood conclusion. Success in this activity will require completion of the plant's automatic control system, extensive operation coupled with thorough evaluation of the plant's performance and operating requirements, and dissemination of test data and operating experience to all interested parties. In defining the remainder of the Solar One program, the overall aim must be to maximize the benefit to the country of the extensive public expenditure to date, rather than to seek an expedient path for completing the experiment at minimum incremental cost. The outcome of the Solar One experience will have far greater bearing on any subsequent initiatives in solar thermal central receiver systems than any other single activity.

In addition, the DOE should cost share with industry on programs that will prove advanced receiver and thermal storage concepts. One such test, which is being organized under EPRI auspices, is the Molten Salt Electric Experiment at the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico.

The private sector is actively pursuing various avenues to move the technology out of the demonstration phase. For example, the recently issued Solar Program Opportunity Announcement by the Southern California Edison Company for the construction of a pre-commercial plant* by 1988 is seen as a critical first step to commercialization. However, these efforts by the private sector assume continued Federal support, including operation of Solar One, system and component develoment and tests at CRTF, cost-shared support for repowering, and the extension of the business energy tax credit beyond 1985.

3. Parabolic dish

The DOE should redirect its emphasis to the parabolic dish program for further technology development because of its potentially higher efficiencies and lower costs. Future component research should concentrate on areas that will either significantly improve known efficiencies, extend the useful life, or reduce the capital and operating costs of the modules. Small multi-module experiments should be programmed on a cost-sharing basis. The ability of the parabolic dish program to pursue three heat engine options needs to be evaluated in relation to the long-term market requirements and the availability of complementary Federal funds in the automotive engine R&D programs.

*A pre-commercial plant is defined as a custom-made, first-of-a-kind facility whose components are not yet in commercial production.

4. Hemispherical Bowl

Hemispherical bowl technology, specifically the Crosbyton Project, has had $4.0 million in FY 82 appropriated from the Solar Reserve Fund. Continued funding of this project in FY 83 and beyond would be undesirable, especially considering the Panel's overall recommendation against large scale demonstration projects. The inherently low average annual collection efficiencies, high thermal piping losses and a rather isolated market pull, discourage further R&D support for hemispherical bowl technology.

5. Solar Ponds

The Panel is not convinced of the prospects for solar pond technology. In view of the foreign leadership in solar pond technology the Panel recommends the maintenance of only a small technical staff to monitor progress in this field. Should DOE find it appropriate, specific research and development may be warranted in the future.

6. Demonstration Projects

No new large scale demonstration projects can be advocated under the present budgetary constraints. The only role for the DOE would be to provide data acquisition equipment and data reduction costs in order to improve technology transfer throughout the industry.

7. Technology Base R&D

The DOE basic and applied research program for solar thermal must achieve a sharper focus based on anticipated availability of first generation technology. Priority should be given to optical, thermal and structural materials; the sciences of thermodynamics, heat and mass transfer; and fuels production.

Many of these research areas will produce results useful to all the solar thermal technologies.

The Federal role should be to coordinate generic research needs in all the solar thermal areas. These include reflective and ceramic materials, operation of vital systems level experiments for technology transfer, and participation in the second generation of component development.

8. Summary of Private Sector Roles

The parabolic trough industry has indicated the existence of entrepreneurial interests in marketing its first generation systems for both industrial process heat and electrical applications, provided private financing can be obtained. The private sector will provide the system level engineering required for large scale sales. The central receiver industry is similarly pursuing first generation sales but there is a far greater need to rely on development of future components, volume sale of heliostats, and continuation of the energy tax credit. The parabolic dish industry will be required to perform R&D and engage in small, system level experiments on a cost-sharing basis before first generation technology will be ready for the marketplace. The hemispherical bowl and salt pond technologies do not appear to have an industrial participant that would undertake, on a cost-sharing basis, the technical and economic risks of the proposed demonstration projects.

VI. WIND

A. Critical R&D Issues

Since its inception in 1974, the Federal wind turbine program has shown progress and has demonstrated that wind machines may be among the first of the solar energy technologies to be economically suitable for use by utilities.

Development and testing of small wind machines (less than 100 KW), supported by the DOE wind energy programs, is well along, and market development is underway by more than 35 private industrial companies. Small wind machines should achieve a significant market, on the order of several tens of millions of dollars annually, in remote site applications. However, it may require 5-10 years to achieve this maturity.

The largest market appears to be for the intermediate-to-large machines. The MOD-5 machines (the third generation of larger machines) are now in the preliminary design stage and are expected to result in machines that could, in quantity production, be competitive for grid-connected applications in parts of the United States.

Research issues remain on development of wind technology over the long term. The analytical tools used to predict aerodynamics and structural dynamics design have been adequate so far, but are based on limited theory and mostly empirical data. Further progress in design, both from the standpoint of efficiency and the reliability, will be hampered without better information. There are unresolved problems in atmospheric fluid dynamics, aerodynamics, structural dynamics, system interactions, materials, and fatigue. Many of these are generic to all sizes and to both vertical and horizontal machines. Much of the research in this area is empirical and can only be pursued through adequate testing of scaled-up machines.

The large wind machines pose additional problems with the design of large structures with unproven materials (wooden rotors or blade tips and 400-foot diameter rotors). In addition to size, a primary technological advance in the Mod 5 design is the use of multiple or variable speed operation which provides higher energy capture, particularly during lower winds. The structural dynamics of these large machines present design challenges and are viewed as high risk until proven by full-scale machine testing. Structural model development incorporating variable speed performance is being carried out but must be tested. Additional advanced technology being incorporated in the Mod 5's includes integral gear boxes and large scale use of wood-epoxy materials. Aerodynamic questions remain for thick airfoil operation in a regime of significantly varying wind velocity and direction over the disc of the blade, extending from roughly 50 to 450 feet off the ground. There have been control problems related to the short time variations in wind energy as well as wear and fatigue problems. Solutions should be defined and verified.

The current generation of multi-megawatt machines (MOD-2 and WTS-4) offer the chance to evaluate advanced design features for later incorporation into the subsequent commercial designs. Five MOD-2 (2000 KW rating) machines are in operation. Three of these are in one location (Goldendale, Washington) and are operating as a first large "wind farm." These machines have some potential for commercial application in areas where the wind resource is very good and fuel prices are high. The MOD-5 machines should lower the cost of electricity by up to 25% as compared to the MOD-2 under similar conditions.

The most significant controversy in the wind program is the timing of the MOD-5 machine and the Federal role in it. It is widely held that, regardless of the view held about the practicality of such large machines, wide-scale utility use of wind probably will not occur until the advent of the large machines. Further, the operation of the smaller machines will not in and of itself provide the information needed to confirm the advance design of MOD-5.

The environmental issues related to wind turbines include the use of land (roughly 26 acres per megawatt including multiple use clear areas, while each turbine uses about 1/2 acre of land), esthetics, and the potential for television interference and acoustic noise under certain cirmumstances. Studies of mortality to migrating birds flying into towers and blades should be continued although the results of past studies suggest this should not be a major problem.

B. State of the Industry

The small wind turbine industry is now selling roughly 1500 machines a year. Although there are a few prominent manufacturers, the industry is characterized by small companies involved in product development and production. There is a fairly high turnover and because of their fragile position, very few are going into R&D.

There are five key U.S. participants in the larger machines: Boeing Engineering & Construction Company, Hamilton Standard Division of United Technologies Corporation, General Electric Company, Bendix Wind Products Company, and Westinghouse Electric Corporation. Only Hamilton Standard now has any significant production facilities.

While technological development of the wind turbine is progressing, the market for wind turbines is highly uncertain. Electric utilities are experiencing a prolonged period of low load growth, low profitability, and extreme difficulty in capital formation. Energy tax credits, PURPA, and more liberal depreciation allowances for small power producers have given rise to a new type of entity, the third party power producer. The third party power producer is an unregulated owner and operator of electrical energy producing equipment who sells power to a utility at a negotiated price based on avoided cost. As a result, a number of letters of intent have been signed between utilities and third parties for power purchase. To date only a limited number of wind machines have actually been ordered and placed in service.

Uncertainties in such key areas as fuel prices, interest rates, inflation, and the continuing availability of the Federal and State enacted tax incentives have weakened the near-term outlook for wind turbine sales. In addition to the purely economic factors, the relative immaturity of the wind turbine industry in both technical and business matters is a cause for concern to potential buyers. Early wind turbines are expensive, further eroding the potential market.

As a result of these uncertainties, the companies involved in the MOD-5 wind turbine program see the risks to industry of bearing alone the remaining cost of development and commercialization as too big. The MOD-5 contractors have stated that continued Federal support for the design and testing of these machines will be necessary through 1984. If the MOD-5 machines are not developed, the potential for significant wind energy production will undoubtedly be delayed.

Foreign governments have programs similar to the U.S. program. Denmark is most advanced and has concentrated on small to intermediate sized machines. Sweden, Germany, Italy, France, England, Belgium, Japan, and Canada all have programs of modest size, with wind machines up to 3 MW. One U.S. company (WTC, Inc.) won a competition in England (Central Electricity Generating Board) to design and construct a test machine of intermediate size having built several units in the United States. Hamilton Standard is involved in the Swedish program. Overall, the foreign competition can be viewed as a real but not yet serious threat to wind manufacturers in the U.S.

C. Transfer of Federal R&D

The DOE program has ensured that developed technology is made available to interested parties by using several technology transfer mechanisms. For instance, system design and development projects have been contracted to private industry. Publication of data and experience has been standard practice. In the case of small wind machines, at least one private company has used the drawings developed by another contractor under Federal funding as the design base for its own machine.

D. Recommended Federal and Private Sector Roles and Objectives

1. Large Wind Machines

The DOE should continue data gathering, analysis, and publication of test results on the three MOD-2 machines at Goldendale, Washington, for two years of operation. Data requirements include wake interaction, noise, TV interference, performance vs. wind speed, structural dynamics, operation and maintenance costs, and reliability.

The Panel assigns a lower priority to Federal funding of the MOD-5 program. Consistent with an assumption of overall continuity in funding at the FY 82 solar budget level, but only under such a circumstance, the Panel recommends completion of the cost-shared Mod-5 development program. DOE funds should support detailed design and testing of two machines, and private companies should fund all hardware, construction, and installation.

Except for generic research and development in special topics essential to longer term advancement of the state of the art, as noted elsewhere in this Chapter, completion of the MOD-5 program should signal the termination of all further DOE support to this technology area.

DOE should consider cost sharing of the data accumulation and analysis on the Hamilton Standard WTS 4 wind machine purchased by the Department of the Interior and installed at Medicine Bow, Wyoming. The Department of Interior does not have a direct interest in the data, but it is important that the DOE obtain operating information on these machines for the benefit of the industry as a whole.

2. Small Wind Machines

Federal support for small wind demonstration projects should be phased out after 1985. However, low-level funding for analyses and testing of current projects should be continued to support the fragile small wind industry. Operation of Rocky Flats, which provides test facilities for these machines, should also be continued, but testing costs should be paid by those requesting the tests. Continued operation of the test facility should be contingent upon continued industry support.

3. Technology Base

The DOE should continue to fund research to improve understanding of aerodynamics and wind distribution, structural response, design tools, models, and to explore advanced concepts and fundamental properties of materials. DOE needs to hand over the research on interaction with utilities to the utility industry, possibly through EPRI. In addition, the DOE should transfer its knowledge to other levels of government, such as the states, in order to provide more site-specific resource information.

4. Private Sector Roles

Industry should assume a large share in the cost of the MOD-5 Program by financing the cost of all hardware, installation and construction.

The private sector should also develop innovative funding methods to help spread risks and accelerate market development as prudent business risks justify, making further investment in improved machines, production capability, and warranty of products.

In addition, it should work with Government in the development of technical standards and participate in DOE program reviews.

VII. OCEAN THERMAL ENERGY CONVERSION (OTEC)

A. Critical R&D Issues

Ocean Thermal Energy Conversion (OTEC) uses the thermal gradient of up to 22^{o}C between the warm ocean surface waters and cold water drawn from depths of up to 1000 memters to operate a rankine system. In view of the low Carnot efficiencies possible for the system, the large size of all mechanical and structural components--particularly heat exchangers--becomes one of the significant cost drivers in OTEC's economic viability. As noted in an April 1981 General Accounting Office study, the commercial potential of OTEC in the United States and elsewhere remains to be determined. Presentations before the Panel indicate that this deficiency was not resolved before the DOE decision to fund only two designs for a shore and shelf based OTEC pilot plant.

Although preliminary estimates of the cost of pilot and full-scale plants were made, many remaining engineering issues make these cost estimates subject to verification by experience. For example, until the cold water pipe has been designed for shelf and shore plants built, and then operated through at least part of its lifetime, the cost of this major item will not be completely understood. For such reasons, the design and construction of the pilot plants must be considered a necessary step in OTEC development. DOE's course has decisively steered the U.S. OTEC program toward the U.S. island and foreign based energy economies in the equatorial regions where the thermal gradients are greatest. DOE chose this path because it appeared that the engineering challenges, particularly with the 1000 meter cold water pipe and electrical riser cable (for grid connected plants only), are greater in the moored and floating plants. Therefore it is necessary to discuss the OTEC program in two parts: shore-based and floating OTEC plants. We note that the Federal program in floating OTEC plants has been discontinued. Although there was some synergism between the two programs, it was not in the areas of greatest engineering concern.

1. <u>Shelf or Shore-Based Plants</u>

a. Bio-fouling

While data obtained from OTEC-1 testing off Hawaii and off the coast of Puerto Rico show that bio-fouling can be controlled by regular chlorination and occasional brushing, the near-shore plants are expected to experience high fouling rates. Data are needed for specific sites.

b. Cold Water Pipe

Design, construction and deployment of the pilot plant and full sixe plant cold water pipes will be major challenges, particularly at the angles deployed in these sites. Each design will be specific to the type of site and platform.

c. Site Location

Each concept for plant foundation has its own set of engineering considerations. The current Phase I contractors are studying tower and land-based sites near steep offshore slopes.

d. Environmental Impacts

The critical environmental issue is the effect of cold water plume re-entrainment on the thermal resource (ΔT). This problem is true of all OTEC plants, but probably is of greatest concern for near-shore plants. The potential for re-entrainment and larger plume residence time on the inshore side of the tower is minimized by the use of the deep discharge, parallel to the prevailing seaward undersea current.

Site specific data on undersea currents will be needed for plume dynamic analyses (both two and three dimensional). At the same time, data are needed on the impact of pumping and the cold water plumes on fish and other biota.

Further research work, again of a site specific nature, will be required to assess the environmental impact of bio-fouling control measures, particularly chlorination, in order to satisfy requirements of a site specific Environmental Impact Statement.

2. Floating and Moored Plants

R&D issues for floating plants are deployment and testing of a large diameter 1000 meter cold water pipe, bio-fouling, and enviromental concerns listed above.

It seems clear that, all other factors being equal, the floating and moored plants will be somewhat riskier. The Panel was disappointed to learn that the large expenditure of federal funds for the one megawatt floating OTEC-1 project netted only 3 months of at-sea test data rather than the scheduled 36 months.

3. Moored Plants Only

R&D issues include mooring ability in sites with multi-directional currents, riser electric cables, electric swivel joints, and allowable electrical transmission distances to shore.

4. Free Floating Plants Only

The major issue is the economic conversion of the electricity produced to a transportable commodity with a sufficiently attractive market.

5. Open-Cycle OTEC

Reduced heat exchanger costs and the production of fresh water are the principal advantages of open-cycle OTEC while disadvantages include larger turbomachinery. Thus, a scale-up experiment will be necessary if this technology is to proceed.

B. State of Industry

The emerging OTEC industry consists of several major companies whose traditional businesses include supplying the defense, aerospace, electric utility, and oil field markets. These large firms are augmented by a variety of hardware component suppliers and engineering and environmental consultants. To date, the industry efforts have been limited to technical and economic system studies, and laboratory or small scale field development activities, largely funded by Federal and State agencies. It is not certain whether any company has accumulated enough information to commit to a major investment in a large scale OTEC plant or the production facilities required to supply OTEC components.

Unlike the traditional electric utility market, there are no established roles in system design and integration or in the relationships between component suppliers and end users of the system. Nor is it clear that utilities will be the prime customers for early OTEC plants. Present tax and loan guarantee incentives may favor third party ownership and the sale of power to utilities. The industry is most likely to succeed first in certain chemical production and in remote power applications. With a modest budget for Federal research and preliminary design, and the continuation of the current tax incentives, commercialization by private industry is possible.

C. Recommended Federal and Private Sector Roles

The Panel recommends against supporting any large-scale OTEC demonstration projects. However, the implementation of the present DOE program plan to complete Phases I and II of the 40 MWe plant appears reasonable under the circumstances. The Panel is encouraged by DOE statements that the industry will complete Phases III through V (detailed design through operation) by using non-Federal funds and the significant economic incentives available through the tax credits.

A significant amount of risk sharing with the DOE will be required of the two remaining teams who successfully bid the Program Opportunity Notice (PON). The remaining R&D effort and the preliminary designs would have to be completed within the appropriated FY 82 budget under the Administration's proposal. This willingness to assume the technical and economic risk should be a major criteria for DOE in its decision to proceed with one or more Phase II contracts. The mooring and floating plant sector have indicated that privately funded work might be possible. If true, DOE should endeavor to transfer the technology from the PON activities as rapidly as possible.

In summary, OTEC has potential as a long-term energy source and as an export technology. The DOE should support Phase II assessments for the current OTEC 40 MWe scale-up, but with limited funds, and should not proceed with construction at this time.

The OTEC budget should not be eliminated entirely for FY 83. A modest effort should continue in support of private investment in basic materials for OTEC components, such as the shore and shelf cold water pipe, heat exchanger, and similar activities, as well as for resource and environmental assessments.

VIII. BIOMASS

A. Critical R&D Issues

The fuel produced from biomass in the United States today is estimated to be about 1.9 Quads (Q)[1] gross, or about 2% of the total U.S. energy consumption of 78 Q. With appropriate research and development, biomass could potentially supply the nation with about 10 Q gross by the year 2000.

Most biomass energy options must be considered as a combination of two key factors: the resource base and a conversion technology to convert the resource into a usable product, fuels or chemicals. Critical biomass R&D issues can be grouped around these two factors.

1. Resource Enhancement

The most critical limitation to increasing energy supplies from biomass is production of biomass, that is, increasing the size and use of the resource base. The two major sources of biomass are forestry and agriculture. The productivity of the U.S. forest land-base is now substantially below its potential. Productivity can be increased by using cultural practices to maximize biomass yields, while at the same time employing sound soil and water conservation practices. Forest productivity might even be doubled in some locations by applying sound cultural practices more widely and by developing new technologies to reduce losses, especially from insects, disease, fire, and poor nutrient management. However, all of these silvicultural problems will probably become more difficult to manage with intensive, forest monocultural production.

The major advantages of both hard and soft wood forest biomass over all other biomass resources are their abundance and low cost in many regions of the

---

1 1015 BTU

country. Wood is an important fuel in homes and industry, and its use as a fuel will grow, although potential air pollution questions must be addressed.

For agricultural biomass, the key issues are environmental degradation, economics, and competition with high value food and fiber production. U.S. agriculture for the last 50 years has suffered from serious soil erosion, and any effort to remove crop residues for biomass energy will intensify erosion and environmental degradation. Agriculture currently uses 1.4 billion acres or 55% of the total U.S. land area for production. High quality lands are employed for crop production while the marginal lands are used primarily for pasture or rangeland for cattle and other livestock. More intense use of marginal lands is projected in the future for grass-fed livestock as world demand for grains rises to feed a rapidly growing human population. Thus, the use of marginal lands for biomass energy production and agriculture will be in direct competition.

The main difficulty in making use of livestock wastes for biomass energy is the economics of collecting and transporting these resources and converting them to useful energy when they contain 80% water.

Aquatic plants, particularly some algae, can produce large quantities of biomass, including hydrocarbons, per unit area under controlled environmental conditions. The major limitations with algae production are the shortage of suitable aquatic environments and the difficulty of processing algae, which are about 95% water. Only 2% of the United States is covered with water and only a small percentage of this is suitable for algae production. Artificial ponds are costly and could impinge upon lands needed for agricultural and forest production.

The production of methane is possible from sewage and livestock wastes, a process which might be built into a waste processing system. However, one of the major limiting factors that requires further research is the effective management of the microorganism complexes involved in methane production.

Although some methane fuel can be produced with digesters, the inputs necessary for conversion of the wastes are relatively large. Thus, the net yields in fuel range from zero to 15%.

Environmental and social costs are significant potential limitations to increased production and use of the biomass resource base. Both are key R&D issues. Most biomass for energy production must come from forestry and agricultural production. In the United States, agricultural and forest production occupies 80% of the total land area and consumes 83% of the total water withdrawn from surface and ground waters. Opportunities do exist to combine agricultural and forest production with biomass energy production. However, changes would have to be made in many current agricultural and forest production technologies. Otherwise, some of the existing environmental problems associated with agriculture and forest production would be intensified. Removal of large quantities of biomass for energy production would intensify soil erosion, water runoff, and nutrient loss problems. In addition, the conversion of natural ecosystems into energy-crop plantations will alter and often will reduce the habitat and food sources for wildlife and other biota. At the same time the new monocultures will be highly susceptible to pest outbreaks.

On a more positive note, some biomass energy options provide important environmental and social benefits through use of waste streams which must otherwise be disposed of. These include municipal solid waste, livestock wastes, and sewage effluent. In these technologies, key issues are lowering costs and improving efficiency and reliability.

2. Conversion Technologies

The second major grouping of critical R&D issues for biomass energy production are associated with conversion technologies. Since resource limitation is the prime constraint for a major biomass energy program, conversion is of secondary importance. Conversion technologies include those which use biological pathways (fermentation, anaerobic and aerobic digestion), or non-biological pathways (combustion, thermochemical, gasification, liquifaction, and chemical). In addition, most biomass feedstocks are dispersed and must be collected and transported and undergo some measure of pretreatment (mechanical shredding , pelletizing, or dewatering) to improve conversion efficiency.

R&D issues exist for almost all of these conversion technologies. However, priorities for research are in biological and thermochemical gasification, liquefaction, and chemical conversion. Priorities for research should also be based upon the most urgent national energy need, such as liquid and gaseous fuels.

A related issue is that some conversion technologies--and, for that matter, some biomass feedstocks--are best suited for production of high value chemicals (rather than comparatively low value fuels) which would otherwise be produced from petroleum feedstocks. The critical point here is that an appropriate balance be attained between production of fuels and chemicals in the national biomass research agenda.

Conversion technologies may use solar thermal energy to affect processes resulting in foods or chemicals. A basic or applied research agenda in this area (also mentioned earlier in the section on Solar Thermal Technologies) has yet to emerge and be evaluated.

B. State of the Industry

The biomass energy industry is more diverse compared to other renewable industries and is difficult to characterize. It includes manufacturers of biomass energy systems and components, pollution equipment manufacturers, producers of chemicals and fuels (especially alcohol), industries such as the forest products industry which use by-product biomass wastes as a principal boiler fuel, some small utility boiler use, and a growing residential wood use industry.

The dominant use of biomass energy in the U.S. currently is the use of biomass wastes and residues as boiler fuel to produce process steam and some electricity by the forest products industry. This industry produces over 50% of its energy needs from biomass, accounting for most of the total biomass energy of 1.9 gross quads produced in the U.S. today. The kinds of wood biomass being used include mill residues [about 72 million tons/year, (MMt/yr)], logging residues (4MMt/yr), and forest thinnings (2MMt/yr).

Some wood is burned directly to heat residences. Most fuel wood is supplied by small businesses probably employing only 2 to 5 persons per unit. Annual use is about 30 MMt/yr.

Where available, baggasse (4 MMt/yr) is used for heat energy in sugar cane processing plants and, in some instances, to produce electricity.

Yearly, about 1.1 MMt/Yr of corn is being processed into alcohol for use as gasohol. The industry is dominated by a handful of producers. In 1980, from 100 to 105 million gallons of fuel alcohol was produced, but about 60% was from one producer. The alcohol fuels industry is located primarily in the Midwest. Overall, the growth in this industry has been limited largely by rising grain prices and a reduction in some subsidies.

Like all other biomass conversion technologies, profitable conversion of grain to alcohol involves a high ratio of cost of raw materials to cost-of-goods produced. In terms of cost-of-goods produced for 1981, the cost of grain in industrial dry-milling-alcohol plants at best conversion efficiencies was about 81% gross. The effects of inflation on labor and processing costs are smaller than the effect of increases in grain costs. If grain use for U.S. fuels significantly increases, then food-feed/fuel conflicts are projected. The new trend in marketing strategy is to emphasize ethanol as an octane enhancer when mixed with premium unleaded gasoline.

The alcohol fuels industry relies heavily on Federal and state tax incentives. Major refineries are moving to states with favorable tax incentives and excise tax exemptions, which for some states can bring the total Federal-state subsidy to as high as $1.35/gallon of ethanol. According to industry, repeal of the Federal 4¢/gallon excise tax exemption would be a major blow.

A small amount (0.001 Q) of methane gas is being produced from about 1 MMt/yr of manure. Most of this biogas is being produced on large cattle farms and feedlots for use directly on the farm. Biogas is also produced as a by-product in sewage processing and is used during winter months for heating the digesters.

R&D is being carried on by the U.S. biomass energy industry, but like the industry itself, it is difficult to characterize or quantify. Both resource base production R&D and conversion technology R&D are being sponsored by the private sector, although the emphasis seems to be primarily on conversion technology where breakthroughts would yield quicker returns and where proprietary interests can be better protected. Specific areas of private-sector R&D investments include anaerobic digestion of animal wastes, low-BTU gasification, and conversion of wood to alcohol fuels. There is limited private-sector R&D in medium-BTU gasification, direct liquefaction and pyrolysis. In the production of resources, there is some private R&D in short rotation woody crops (primarily from pulp and paper production) and in terrestrial and aquatic energy crops. There is no significant private-sector support for generic research in municipal solid waste. Some R&D investments are being made in the alcohol fuels industry, by operators of medium and large plants, primarily to improve process efficiencies and reduce energy costs.

Finally, the Gas Research Institute, a nonprofit, utility funded R&D corporation is also involved in biomass energy R&D. Research there is examining several biomass feedstocks and conversion technologies to produce methane.

C. Transferability of Federal R&D

To date there have been no major advances in the U.S. biomass energy program from either Federal or private industry R&D. If an important breakthrough in technology in raising the productivity of forest or agricultural biomass for energy conversion is made, this technology could be transferred rapidly to the private sector through the cooperative extension program of the Department of Agriculture. Other means of technology transfer include industry participation in DOE programs, program review and definition of research needs by industry, and through scientific meetings and publications.

Generally, it appears that technology transfer between government and industry has been weak, and a stronger relationship exists between industry, universities, and the nonprofit R&D corporations. For MSW R&D in particular, the industry identifies technology transfer as the major nontechnical, institutional barrier affecting implementation of new technologies. Industry does make use of federally based biomass R&D facilities, particularly the U.S. Forest Products Laboratory and the USDA Regional Laboratories.

D. Recommended Federal and Private Sector Roles and R&D Objectives

1. Federal Role

The Panel has found that the national research agenda for biomass energy needs a solid conceptual framework. The biomass R&D agenda seems to be an agglomeration of ill-fitted programs, and the situation seems too amorphous to allow for effective evaluation and management. This has primarily resulted from the historical growth of biomass programs and the way these programs were created. There is an urgent need to implement a new comprehensive framework for the nation's biomass energy R&D program that sorts out objectives, priorities and responsibilities.

a. Basic research in understanding and expanding the resource base: The Federal Government should continue its lead role in resource assessment, including estimates of biomass production and feedstocks, the location and availability of unused wastes, and other basic data collection activities. In addition, primarily through the USDA and the universities, the Federal Government should conduct basic research to expand the resource base of both terrestrial and aquatic plants through plant species screening and selection, cataloging of plant components to identify potentially valuable chemicals, phenotype collection, insect and disease management, agronomic studies, and basic research in photosynthesis, photochemistry, electrochemistry, metabolism and other fundamental aspects of plant physiology.

b. Expansion of the technology base for production and conversion technologies: Federal activities in expanding the technology base should include basic research in biological and thermochemical conversion of biomass, especially lignocellulosic materials. Increased consideration should be given to the development of chemical feedstocks which may have a higher value than fuels, as well as the use of hydrogen as a co-feedstock with wood. As part of this effort to expand the technology base and to enhance technology transfer, the Federal Government should establish a biomass standard reference sample repository, as has been done with coal, in the National Bureau of Standards. Priorities should emphasize development of the forestry resource base and secondarily, conversion technologies.

c. Analysis of critical environmental and social issues: Perhaps more than any of the other solar technologies, biomass energy faces a number of serious environmental and social issues which will doom this technology if not resolved. These issues are no less real than hardware-related R&D issues, and they are equally in need of objective research. They include: soil erosion, nutrient loss, water use, water quality degradation, air pollution, introduction of exotic plant species, loss of fish and wildlife habitat, and competition with food and fiber production.

The Panel is concerned that the apparent declining role of DOE and EPA in environmental research means these issues are not being adequately addressed. As with the environmental and social issues associated with other solar programs, it seems unlikely that the private sector will support adequate R&D in these areas.

A major social issue of concern is occupational injuries. For example, harvesting woody biomass has an occupational injury rate that is 14 times greater per million BTU than that of underground coal mining. Research is needed to reduce the hazards of biomass harvesting and use in the agricultural and forestry sectors.

d. Improvements in technology transfer: The apparent weakness in technology transfer between Government and industry, which was reported to the Panel, may be a function of the diverse character of the industry. Since it has also been reported that industry communicates well with the university agricultural extension services, and nonprofit R&D corporations, DOE should perhaps direct more of its technology transfer activities through these channels.

e. Other Federal issues:

The Federal excise tax exemption of 4¢/gallon for alcohol fuels appears to be essential to the growth of the alcohol fuels industry, and the industry may have lost investments from discussion of proposals to repeal the exemption. Nevertheless, there is no apparent economic rationale for this special subsidy.

2. Private Role

The private sector should have primary responsibility in biomass energy R&D in the following areas:

a. Continued improvements in commercially proven technologies: The private sector should conduct R&D to improve the performance of commercially proven technologies, such as some fermentation technologies and combustion, and to improve pollution control technologies. The reward of lower energy and production costs seems adequate to drive this R&D.

b. Demonstration of near-commercial conversion technologies: The private sector should take the lead in demonstration projects, including pilot plants and scale-ups. There is a risk that this will delay introduction of competitive technologies into the market place, but it should prevent premature scale-ups which have occurred in biomass technologies in the past.

c. Basic research in genetic engineering: Genetic engineering to improve biomass production, which allows direct production of hydrocarbons in biomass conversion, is an area of high-risk, potentially high-payoff R&D which clearly fits the new Federal role under the Administration's policy. However, it appears to be an area of particular interest to the private sector and does not appear to need major Federal support.

IX. BUILDINGS SOLAR ENERGY RESEARCH

A. Critical R&D Issues

Heating and cooling of buildings and supplying their occupants with hot water accounts for more than one-third of the energy used each year in the United States.

The building industry and the solar equipment supply industry are composed of a large number of small companies and independent builders and suppliers which have neither sufficient scientific and financial capability, nor the incentive to undertake research in energy conservation and renewable energy technologies. Trade associations (notably the National Association of Home Builders) have conducted applied research but this has been generally directed toward making their products more readily marketable over the short term.

The DOE program in this area has undergone a number of transformations. The current program is rather fragmented. There is a Buildings Energy Research Division in the Office of the Deputy Assistant Secretary for Conservation. There are also an Active Solar Heating Program, and a Passive Solar Program, both in the Office of the Deputy Assistant Secretary for Renewable Energy. These have been organized around individual technologies, rather than as a comprehensive program aimed at improving the overall energy performance of buildings. They also have placed insufficient emphasis on the need for technical and other information by the individuals and businesses that supply, design, construct, and use buildings.

Active and passive solar heating and cooling technologies and related conservation strategies are aimed at providing living and working environments which are comfortable and properly illuminated.

Conservation features frequently are indistinguishable from passive features. Often, active and passive features are technically and economically sound only when considered simultaneously as a part of integral building design. The thermal, structural, and esthetic properties of materials and appliances, and their arrangements in building designs are the determinants of the building performance and cost, and thus of eventual marketability. The Panel therefore is raising the issue of the organization of DOE research in this area as a critical research management issue.

A number of spokesmen for the building industry stressed the need to convert research results into concepts and language which are practical and familiar, as a prerequisite for use by the appropriate segment of this diverse set of industries. In particular, conventional U.S. measurement units should be used instead of Metric (S.I.) units in publications intended for the building and heating, ventilating and air conditioning industries.

The energy and lighting performance and design practices and the economic environment of single-family residential buildings varies dramatically from those of multi-family residential buildings and commercial buildings. In addition, there is a greater understanding of the energy performance of single-family residential structures than either multi-family residential or commercial structures. The R&D needed to improve the energy performance and cost of the more than 80 million existing structures is also considerably different from that designed to modify design practices for new buildings. R&D programs should reflect this distinction. Critical R&D issues that should be addressed in the Federal program are listed below:

Single-Family Residential Buildings, New and Existing

-- New useful materials for collection and storage of solar energy and for glazing for residential buildings

-- A research effort integrating solar systems with conventional heating and cooling systems

-- Performance testing to document the performance of lighting, heating and cooling systems and for analysis of the degradation of performance (e.g., organic fluids, corrosion, scaling)

-- New retrofit materials and techniques for mitigating infiltration and conduction losses

-- Intensive research in dehumidification using both new materials and systems

-- Analytical efforts to understand heat and mass transfer in buildings with complex geometries, with or without forced convection and storage. Verification of models to establish their reliability should be a part of the analytical effort.

Multi-family Residential, and Commercial Buildings, New and Existing

-- Research into innovative cooling materials and systems (e.g., desiccants, phase change materials)

-- A basic understanding of heat and mass transfer in complex geometries, in the presence of storage, both with natural and forced convection

-- New building shell and glazing materials with selectively favorable thermal optical and structural properties (e.g., thermal insulation)

-- To reduce the heat load from electric lighting, an intensive research effort should be devoted to developing advanced daylighting strategies and to integrating daylighting design with HVAC systems and controls.

B. State of the Industry

An appropriate characterization of industry requires separate consideration of the building industry and the supply industries.

1. Building Industry

Because the building industry is fragmented, with many small to medium-sized firms involved in building construction or in supply of systems and components that go into building, it is difficult for the industry to undertake anything resembling a comprehensive energy research program. Building owners and users are also diverse, including major public and private institutions, small businesses, and individual owners and renters of single-family homes and of apartments. The industry recently has experienced a drastic reduction in construction of new buildings, primarily because of the increase in interest rates. A healthy buildings industry must rely on others for the establishment of a technology base for affordable residences, including shells and appliances which provide light and comfort at reasonable cost.

The building industry is reluctant to use systems that tend to increase the initial cost of the building, no matter how cost-effective the investment is. However, this situation is slowly changing with improved consumer and lender understanding and with increased fuel and electricity costs.

2. Solar Water Heating Industry

Solar water heating is the oldest and most widely used application of solar energy. Today there are several thousand suppliers of solar water heaters, all of which use the products of a relatively small number of large manufacturers of copper or aluminum absorber plates, tempered cover glasses, and fiber glass insulation. Of the several thousand small manufacturers, most are under-capitalized and none has the financial or the technical ability to do research of any significance. Most imitate the products which already are on the market. Many of the large manufacturers which entered the solar field in the 1970's have since withdrawn, including PPG Industries, Exxon and Olin Brass. A few others, including Revere Cooper, Reynolds Aluminum, Owens-Corning and General Electric, remain active. The thermo-syphon water heater has been shown by the Bureau of Standards to exceed all other types in thermal efficiency but it is offered by only a few manufacturers. One reason for the reluctance to use this simplest of all water heating systems is the freezing problem and intensive study is warranted in this area.

3. Active Solar Heating and Cooling Industry

Only a few companies offer the installation of complete heating systems. Even fewer offer complete cooling systems. In either case, the systems are likely to be made to order, and assembled by piecing together components designed for general purposes, and assembled at the job site.

At the present time, there is no active solar cooling industry in the United States and a homeowner who wishes to install an active solar cooling system must look to Japan to find one. Only a few U.S. residences use active solar cooling systems based on the absorption refrigeration principle. The only manufacturer which offers completely integrated solar heating and cooling systems is the American Yazaki Corporation, a Tokyo-based manufacturer with an office in Dallas. The only U.S. manufacturer of heat-activated residential air conditioners is Arkla Industries, the successor to the Servel Corporation.

Hybrid evaporative coolers, which use fans to circulate large quantities of air through moistened pads, are widely used in the southern half of the U.S. and in many tropical foreign countries. These are effective in spring and fall, but they cannot dehumidify and so produce little comfort during the hottest and most humid part of summer.

The indirect evaporative cooler, in which incoming fresh air is cooled but not dehumidified by heat exchange with evaporatively cooled air, is beginning to make a comeback in the arid southwest, where summer cooling is essential to human comfort.

Solar-powered Rankine cycle turbines and engines are under intensive study as power sources for compression refrigeration equipment. The U.S. and the Saudi Arabians have joined forces under the SOLERAS program to build and test a number of systems large enough to air condition small commercial buildings. The test phase was started at the end of summer 1981 in Arizona where the climate is similar to that in Saudi Arabia. Test results have not yet been made available.

4. Passive Space Conditioning Industry

There is as yet no real U.S. passive building industry. The buildings which use passive principles intentionally are usually architect designed or offered by progressive builders who have learned enough of passive principles to incorporate some in their buildings. Passive components are primarily large, south-facing windows made of single or double glazing with concrete floors and masonry walls to provide thermal mass for energy storage. Frame construction can also be used if means are incorporated to store excess heat in the daylight hours for use at night.

Most of the information on passive building design and performance has been distributed by the American Solar Energy Society. ASES holds a well-attended Passive Conference each year at which papers are presented dealing with passive strategies for both heating and cooling. Government sponsored work at Los Alamos, Sandia, Lawrence Berkeley Labs, and SERI has been valuable in acquiring and disseminating information about design and operating experiences with passive buildings.

The viability of the emerging industries supplying components and systems for solar buildings technologies and of a building industry using these or passive concepts and systems in their designs currently depends on the existence of Federal and in some cases state tax credits.

C. Technology Transfer

There has been a growing and a remarkably free interchange of information between the Federal program and private industry and between these and overseas interests. Most of the federally financed projects have resulted in voluminous publications, some of which have permanent value. Information about the Federally sponsored projects is generally available, but because of recent DOE program reductions, future availability is in danger of being severely curtailed if not completely interrupted. Reports on operating experiences with the demonstration projects are particularly important. Publication of these reports in addition to the information from the National Solar Data Network needs to be continued in order to derive maximum benefit from this Federal R&D investment.

It is important to note that commercial energy tax credits are available only for federally approved designs and components. This requirement encourages improvement in the quality of the technologies and installations of systems for commercial buildings.

While technology transfer has been satisfactory, much remains to be done. DOE should ensure that research and development findings resulting from its activities--whether in new materials, new components, new systems, new designs, or new design guides and practices--are useable by appropriate parts of a diverse industry. This should specifically include:

- -- Home builders and construction trades (new buildings)
- -- Homeowners, remodeling contractors, product and system distributors (retrofits)
- -- Architects and engineers
- -- Product manufacturers
- -- Financial institutions.

Symposia, meetings and workshops should also be used to transfer new knowledge, to provide forums for discussion and open debate, and to provide an ongoing opportunity for industry critique of the program.

D. Recommended Federal and Private Sector Roles and Objectives

A strong integrated Federal R&D program aimed at generic research issues is needed to advance solar building technology and should be given higher priority. A successful program will support the important building industry and has the potential for high payoff in reducing the cost of energy in over 80 million existing buildings.

The Panel recommends that DOE establish a buildings solar energy research program that integrates all DOE research and development on solar energy and energy conservation in buildings. Existing active, passive, and energy conservation programs should be continued in this new organization. The Panel also recommends that the program follow the outline discussed in the critical issues section.

To support an emerging solar industry for buildings through a precarious stage of development, the Panel recommends that the residential solar energy tax credit not be terminated in 1985, but rather extended and gradually phased out by 1990. This will provide a reasonable period for adjustment by the industry. Certain buildings R&D activities are clearly the responsibility of the DOE. In addition to the areas discussed in the critical R&D section, the following also should be supported by DOE:

1. Building Performance Data

The performance data of 11,875 demonstration projects mandated by the Solar Heating and Cooling Demonstration Act of 1974 should be analyzed and reported. The performance of 215 commercial building projects mandated by the Act should also be analyzed and made available to the public. The National Solar Data Network should not be discontinued until this reporting function has been completed.

2. Buildings Solar Energy Research Institute

The diversity of the buildings industry, as well as that of solar equipment suppliers, both characterized by a very large number of small builders, has prevented this industry from adequately conducting its own research and development programs. In the past, the Federal Government conducted a variety of product-oriented development programs. As the Federal Government assumes a more generic role in supporting only longer-term research, the lack of an industry supported institute (which might be similar in some respects to the Gas Research Institute and the Electric Power Research Institute) dedicated to the study of energy systems of buildings becomes more apparent. The Panel strongly recommends that DOE initiate discussions with the building trade associations leading to the formulation of objectives, structure, and funding for such an institute. The discussions should conclude with specific proposals for its establishment.

3. Solar Cooling and Dehumidification

New ideas in solar cooling are needed. Cooling is one aspect of solar technology where energy supply and demand are closely matched. Dehumidification is equally important, for the available processes require large amounts of electricity to drive compression chillers. The prospects of developing desiccant systems which can be regenerated by solar energy are good, and the work in this area by SERI should be accelerated.

Absorption solar air-conditioners available today are the only system which can produce dehumidification. The field of absorbent-refrigerant pairs is an area in which fundamental research is needed to find something better than today's lithium bromide water systems. The private sector is not likely to undertake research in this field, but the prospects for high payoff are good if success is attained.

4. Solar Resource Assessment

A central Federal repository should continue for generating and containing the broadest data base documenting the U.S. solar resource. Acquisition and analyses of solar thermal radiation data from the 26 National Weather Service stations and other sources should be funded by DOE. It is highly desirable that a network of night sky measuring stations be established and operated for a long period so a firm data base can be established for calculating night cooling.

5. Energy Storage

Research is needed on energy storage at temperature levels between 4°C (40°F) and 66°C (150°F). This area requires some basic research for application therefore it lies in the range of Federal responsibility rather than the private sector. Phase change materials have been with us for half a century. There is virtually no reduction to practice of the thousands of patents which exist in this field.

6. Materials

a. The life expectancy of materials used in solar collectors, both flat plates and concentrators, is of great importance. It should be a part of the continuing Federal long-range research program to investigate the suitability of existing and new polymers which are proposed as replacements for glass, copper, and aluminum.

b. Corrosion of metal components of solar systems is a problem of the greatest importance, and a carefully integrated research program to understand the mechanism of corrosion could produce results which would be beneficial to conventional HVAC equipment as well as that used in solar systems.

7. Basic Research

Generic research should be accelerated on developing a basic understanding of heat and mass transfer phenomena in buildings. Theory should be tested empirically and verified. The results should be converted to design guides useful to architects, engineers, and builders.

8. Environmental Control

Research should be continued on the health aspects of lowered air circulation rates in tight buildings and on mitigating ventilation mechanisms.

It should be the responsibility of the private sector to continue to improve water and air heater designs as well as to continue with product development to resolve freezing problems of solar collectors, improve fail-safe freeze protection systems, design efficient systems using low freezing point working fluids, and improve thermo-syphon systems.

X. INDUSTRY-GOVERNMENT RELATIONSHIPS

A. Introduction

In the course of the Panel's technical review of each solar technology it became clear there is every reason to be optimistic over the future of a number of solar technologies, provided that the Federal and private sector relationships are handled with care. Several issues common to more than one solar technology were identified during the technical reviews. The issues related to the specific charter of the Panel are discussed below. In this section we briefly examine and summarize the policy, economic, regulatory and institutional constraints under which the solar industry is operating and how the Federal Government can perform its essential role to complement and nurture growing private efforts.

B. Accomplishments and Potential of the Solar Industry

Overall, the solar technologies--some of which have been important at the regional or local level for years--represent a series of highly promising energy options for the United States, offering both demonstrated technical feasibility and a secure, long term, renewable resource base to draw from.

The promise of solar energy becomes even more important with the realization that current favorable conditions in oil supplies are transitory. The U.S. dependence on unreliable foreign supplies of oil continues to be a vulnerable spot in the nation's economic health, and has potentially serious consequences for national security.

The accomplishments of the solar industry over the past 10 years are often overlooked but are impressive:

- -- 750,000 square feet of parabolic troughs installed
- -- 35 companies putting 1,500 small wind machines into service annually
- -- The start up of the central receiver Solar One project generating 10 MWe
- -- The achievement of a 29% gross and a 26% net conversion efficiency of sunlight to electricity with a parabolic dish/Stirling engine system
- -- A 300% increase in thin film photovoltaic efficiency
- -- A 5-fold decrease in photovoltaic module costs
- -- An 80% increase in the use of biomass as a fuel source
- -- The annual installation of 17 million square feet of solar hot water collectors.

The Panel focused its efforts primarily on the technical status of R&D opportunities in each solar technology area. However, in an attempt to obtain quantative assessments of the potential payoff from successful R&D programs, it sought to avail itself of estimates of the likely contributions to be made by solar technologies. Available estimates varied widely, although realistic estimates suggest a 5-11% solar contribution, excluding hydro. Hydroelectric power generation has been commercially available for many years, contributing significant fractions of total electricity in a number of regions. Conventional technologies of biomass conversion, namely, electricity and industrial steam production from lumber processing residues in the Northwest and home heating by wood burning primarily in the Northeast currently supply about 2% of the national energy requirements. Several other technologies are becoming increasingly more available in the marketplace. Even larger percentages may be supplied in countries well endowed with sunlight, but with no, or few, energy resources in the ground.

C. Current State of the Industry

A healthy solar industry able to invest in itself must evolve to meet long term solar goals. The conventional biomass industry supplies about two percent of the nation's energy needs and is operating in a relatively well-defined marketplace. The remainder of the growing solar industry is currently in a precarious competitive position compared to conventional energy and older industries which are firmly established.

The industry is highly diverse. It includes new-venture and advanced-systems divisions of some large, multiproduct firms whose primary business is in petroleum products, forest products, agriculture, aerospace and defense, equipment fabrication, or others. Far outnumbering these is a wide range of smaller companies for which renewable energy is a central or major business area. The smaller firms, though by nature willing to take risks that others might avoid, are often short of capital, too small to support research and development, and unwilling to bet their entire future by spending large sums on testing and demonstrating major new products. In addition, a large number of entrepreneurial ventures are just getting started.

This variety and activity attests to a relatively vigorous and growing industry, but one that is not yet sufficiently established to withstand either the currently difficult financial market, a well managed and heavily subsidized foreign competition or abrupt changes in both U.S. Government policy and the energy marketplace.

D. Risk Factors

A number of risk factors inhibit a more rapid industrial and consumer investment in solar technologies:

1. From a financing point of view, renewable energy technologies are characterized by a high initial capital investment followed by relatively low annual operating costs, and low or no fuel costs. Today's financial conditions (a slow economy, a high cost of capital, high expectations for return on equity, low expected inflation in the fuel costs of conventional energy technologies) make such capital investments difficult.

2. Tax laws affecting all investment, and renewable energy investments in particular, have either been changing rapidly or are proposed to be changed. These rapid policy fluctuations (as well as uncertainty about policy changes) create major uncertainties about the tax environment in which future capital investments will be made, and have deterred investors.

3. Energy demand and prices have fluctuated. Even though energy demand currently is soft and oil prices have fallen, general expectations are for demand to tighten and for prices ultimately to rise--but when and by how much are highly uncertain. This uncertainty also undermines investor confidence.

4. Technical progress, which has been rapid, may slow significantly if Federal R&D programs are substantially reduced and if key incentives, such as the residential and business energy tax credits, are removed. Without continued technical progress, many of the technologies now attracting investment may not reach fully competitive status in the near future, and the current investment will be lost.

5. How extensively these new technologies will be used is largely determined by their reliability, efficiency, and competitive economics. Because they are new and rapidly developing with insufficient documentation of operating experience to date, investors continue to see them as risky.

6. Compounding the problem of large capital investments required in setting up production facilities to lower unit costs, uncertainties in market development, technology innovations, and foreign competition may render such facilities obsolete over a short time. This risk exposure further delays emerging technologies from moving into commercial production.

E. Federal Role

The Panel recognizes the need for increased reliance on private industry and the use of market mechanisms to commercialize solar technologies to the maximum extent possible. It is even more important now for the Federal solar program to work closely with the private sector to leverage private investment.

1. Research and Development

Basic research and high-risk, potentially high-payoff research and development are important Federal roles. Similar to other endeavors which are not sufficiently focused to warrant private investment, Federal support for these activities enables the development of the scientific and technical basis for an increasing cost-effective use of the solar resource. These activities provide information and knowledge which benefit the country as a whole, and establish U.S. competence in a growing and progressively competitive world market.

Under this policy, the Federal Government retains a critical R&D role to support industry in the development of solar technology. The Panel believes that the proper Federal role should be limited largely to supporting technology base activities, including basic and applied research, exploratory and technology development, and vigorous technology transfer efforts such as operating some key test facilities and programs. Generally, the most commercially promising technologies must be completed through the technology development stage to permit transfer to U.S. industry, although, for some technologies, industry will step in sooner.

Engineering development programs, such as small-scale pilot plants, may be justified in special cases when substantial industry cost sharing is forthcoming. Until recently, this had been accomplished with some form of financial support from the Federal Government. Costly demonstration and commercialization programs by the DOE are not justified under current budgetary conditions. This is not to say, however, that there is no need for demonstration programs--particularly for technologies with potentially widespread application. Rather, the Panel feels that the burden for demonstration and commercialization should be shifted to the private sector to be pursued as market conditions indicate.

Contract research plays an important role in diversifying research, and in building the infrastructure for technology transfer. It should be carried out by using the following guidelines:

- Open competition should be the rule for procurement of contract R&D services, including basic and applied research. These open competitions should involve firms large and small, universities, and non-profit organizations. Awards should be made on the basis of merit and cost.
- Cost sharing should be encouraged. Consideration should be given to minimizing the burden on small, undiversified companies.
- Program review meetings, open to both U.S. contractor and non-contractor industry participants, should be held regularly.

2. Tax and Regulatory Policy

At a time when direct Federal involvement in commercialization is ending, an appropriate tax policy may be the most important factor to provide the bridge necessary for private sector commercialization. The business energy tax credit (ETC), tax credit for solar installations in buildings, and some provisions of the Economic Tax Recovery Act (ERTA) are important for private investment.

For numerous renewable energy projects--wind, solar thermal, biomass projects of a wide variety, and some proposed photovoltaic projects--the energy tax credit has been essential to private financing. By effectively offseting some of the high front-end costs it has made these projects more attractive to investors, enabling the return on investment to be commensurate with the perceived risks.

The energy tax credit also helps alleviate and correct a variety of market defects. It should be emphasized that, despite moves toward deregulation, the overall market for energy is not a free marketplace. Internationally, oil prices are influenced by foreign non-market decisions on production and pricing. Internationally set oil prices have a direct, strong influence on domestic U.S. energy prices. Domestically, producers of traditional fuels (oil, gas, coal, uranium) have special tax treatment for the costs of extraction, depletion and use that continue to be important in stimulating production and in obtaining needed capital. Federal and State regulation continues to control the prices of natural gas and electricity.

For these reasons, the business energy tax credit and the buildings solar tax credits should be extended until 1990 to help ensure introduction of solar technologies. A specific phasedown schedule, starting in 1986, needs to be set for industrial planning. The R&D tax credit cannot take the place of the business energy tax credit because it applies to all R&D and will not, in the Panel's view, be a major factor in the private sectors' moving ahead. However, the R&D tax credit can be improved by expanding it to include new business to provide further incentives for private solar R&D from new sources. These measures will produce a more stable investment climate for the solar industry by reducing the uncertainties of Federal tax policy and will allow industry to carry out its new leadership role.

In sum, the business energy tax credit helps offset the inherent advantages for fossil energy sources implicit in the U.S. tax system. The tax laws generally favor energy sources with high annual fuel costs and tend to work against the solar technologies with comparatively high capital costs but little or no fuel costs.

The tax advantages for alcohol fuels are considered by the Panel to be a different matter. Rather than correcting for market imperfections, the tax exemptions and advantages for biomass alcohol fuels are essentially a special subsidy. The Windfall Profits Tax Act established and extended through 1992 tax exemptions and advantages for biomass alcohol fuels equivalent to $0.40 for every gallon produced or about $16 a barrel. Several States have enacted accompanying exemptions with the result that the total tax benefit for alcohol fuels exceeds the current retail price of gasoline in some States. Yet planned new production remains relatively low and little R&D on improved technologies appears to have been stimulated. There is no particular need for this subsidy and the Panel recommends that it be eliminated.

The Public Utilities Regulatory Policy Act (PURPA) has played a significant role in encouraging the use of small solar electric technologies. PURPA required that utilities purchase power from third party power producers (i.e., an unregulated owner and operator of electrical energy producing equipment who sells power to a utility) at a negotiated price based on avoided cost. This requirement provides considerable leverage to small producers of electricity and incentive for the utility to negotiate a fair contract. The Panel heard considerable testimony on the importance of PURPA to the health of the solar industry and has concluded that, like the business energy tax credit, it is essential to the survivability of the industry, at least in the near-term.

3. Technology Transfer

If the Administration's energy R&D policy is to be successful, Federal solar programs which produce near-commercial technology should be transferred to industry as soon as possible. Dissemination of documents alone is not effective. Personnel exchange and residency programs, widely publicized program and topical review meetings, and other methods should be sought and programmed. Programs should not be abandoned until it is clear that the technology and knowledge have been transferred in an orderly manner.

Ongoing communication, program planning, and program reviews and evaluations should be designed to involve industrial R&D institutes (e.g., EPRI, GRI, NAHB, others) and industrial representatives. These actions should ensure a mutual awareness of the accomplishments of existing programs to industry and will serve to provide DOE with ongoing industry feedback.

Even in programs scheduled for ultimate phasing out, the Panel concludes that it is important to maintain a basic information and tracking function, to serve as a central focal point for continuing private sector activity. A tracking program would have very modest cost. A handful of people with a modest budget might be required for occasional conferences, symposia, and sponsored state-of-the-art summary publications. These activities help preserve what has been learned. Research that goes unreported might just as well never have been performed.

4. Resource and Environmental Assessment, Testing and Standards

The Federal role should include important technology support functions not likely to be conducted by private industry, namely, solar energy resource assessments, performance testing of specialized materials and components, test facilities programs, assistance in verifying industry-made standards, and assessment of environmental problems and management. A key to gaining market acceptance is an independent testing or verification program. Test facilities are also often a useful research technology transfer tool and should be supported on a reasonable cost-recovery basis with industrial users.

5. Consolidation and Restructuring

Prompted by very rapid growth in Federal funds in the mid-1970's, solar energy activities of various kinds developed rapidly in universities, national labs and in industry. This diversity is basically healthy, assures variety and richness, and reduces the risk of early commitments to less than optimal paths. However, because of extensive recent reductions in the Federal solar budget, the current funding may not be sufficient to support a "critical mass" of scientists and engineers in each of the locations where research and development activities have existed in the past. A consolidation of activities into fewer field offices, national laboratories, and research centers is likely to improve efficiency. Moreover, as the Federal role changes to emphasize research and development (as contrasted with the programmatic, engineering projects of the past) a research management structure should be adopted whereby more management 'uthority is vested in fewer lead centers and research centers.

As the national economic outlook and the prices of energy change, and as the development of a solid solar technology base yields insights on new marketplace potential, the relative significance of the various solar technologies will undoubtedly change. The Panel stresses the continuing need for R&D program planning, technical assessments, systems analysis and program evaluation from inside and outside government to provide an appraisal of program accomplishments and directions.

6. Continuity

Rapid changes and discontinuities in Federal policy and program direction over the last five years have disrupted orderly technical progress and have caused uncertainty and unanticipated costs in the private sector. As the Federal programs complete the transition to R&D, continuity, relative stability, and gradual change become even more important to effective administration than in the past. These aspects may be more important than the absolute amount of money in the budget. R&D is dependent on teams of talented people, trained, assembled, and maintained by universities, laboratories, and firms, at significant cost and with considerable effort. Such teams of talent cannot be turned off and on like production lines; continuity is essential for scientific productivity.

Stability and continuity in regulatory and economic climates are critical for a healthy industry. Without both, firms cannot adequately plan investments and staffing. Industry needs continuity to maintain its teams of people and to maintain commitment, expertise, and strength in important national areas. The same holds true for universities.

There is a need to foster a budgeting climate in both the Administration and Congress which is based on an expectation of continuity. To ensure future consistency and the continuity needed to facilitate private sector commitment, and to stabilize DOE and Laboratory planning and program execution, the Panel urges the Office of Management and Budget to support rolling 2-year appropriations by Congress for solar R&D, with carrover funding.

F. Private Industry Role

1. Demonstration and Commercialization

The primary role of the private sector should be in demonstration and commercialization of solar technologies as market conditions allow. However, the expectation that private industry alone will finance the demonstration of near-commerical, large scale technologies (central receiver, OTEC, some large wind machines) when they are ready for commercial operation, is not always realistic. In the shorter term, the withdrawal of DOE support for demonstration and commercialization of near-commercial, cost-competitive solar technologies undoubtedly would slow the rate at which these technologies would be introduced into the marketplace. A slowdown would create a risk that the U.S. solar industry will not be ready when market conditions improve.

A number of mechanisms currently exist for some segments of industry (where solar technologies are significant) to ensure the role of commercialization and to provide guidance to Federal R&D programs. Notable are the Electric Power Research Institute and the Gas Research Institute. The Panel concluded that these provide an effective link for continuity in technology transfer and commercialization.

To help establish a much-needed scientific link for the building industry and the solar system supply industry for buildings application, the Panel recommends the establishment of a Buildings Energy Research Institute.

2. Electric Power Research Institute and Utility Involvement

The Electric Power Research Institute (EPRI) conducts much of the research and development for electric utilities and co-funds a number of developmental/demonstration projects. As a result of reduced Federal levels of R&D funding, EPRI has reprogrammed research funding in several areas. For example, EPRI funding of the Brayton cycle receiver (Solar Thermal Full System Experiment) tests planned for the Central Receiver Test Facility (CRTF) have been deleted from the 1983 proposed budget because the market for this technology (e.g., hybrid systems) is significantly delayed without Federal involvement. EPRI plans to pursue development of molten salt technology (Molten Salt Experiment) in cooperation with DOE and industry, accelerate technology transfer from existing demonstration projects (e.g., Solar One) and increase its efforts on wind technology during 1983.

The utilities, ultimately the major user of the electric-generating solar technologies, do not have the resources to make major investments in demonstration or prototype facilities because their allowed rates of return are not commensurate with the risks involved. This regulatory imbalance forces utilities to operate in a conservative, risk-averse mode. The industry probably will not make major investments in emerging technologies until adequate technical, economical and operational data have been acquired to reduce risks and major regulatory and institutional barriers have been removed.

With these financial and regulatory constraints, utility efforts, with a few exceptions, are likely to focus on small, end-use projects. Passive systems, water heating and load leveling systems are likely to receive major emphasis.

The issue of the commercialization of emerging technologies was summarized by the U.S. General Accounting Office Report to the House Committee on Science and Technology (EMD-81-145, September 28, 1981): "The electric utility industry had R&D efforts in these areas but because of financial problems, risks associated with demonstration and the large investments required, it will not carry out demonstrations on its own. Without such demonstrations, it is likely commercialization will be delayed or perhaps not occur."

3. Gas Research Institute

The Gas Research Institute is a non-profit private research organization funded primarily by a surcharge to customers of interstate and intrastate pipeline companies and distribution companies, and regulated by Federal, State, or local government agencies. GRI's primary research effort relating to the solar technologies is its methane from marine biomass program. This concept would utilize an integrated process concept. Kelp farmed and harvested in the open ocean would be converted to methane by fermentation. The project was co-funded with the Federal Government through 1980, but, since 1981 has been solely funded by GRI with a total budget of $4.4 million (reduced from $8.7 million).

4. Buildings Energy Research Institute

The need for establishing a Buildings Energy Research Institute, and recommendations for initiating discussions within the industry have been presented in Section IX, Buildings Solar Energy Research.

G. Foreign Developments

Even though the United States still has the technological lead in development of most areas of solar energy, foreign countries are also actively involved. Thirty percent of the 82 photovoltaic cell manufacturing companies worldwide are U.S. based. They account for 80% of the world market. However, Japanese and European companies will increase their market shares in the near future at the expense of U.S. market share. Of particular importance are the coordinated development efforts and government sponsored research in Japan and France. The Japanese emphasis on automated, low cost production techniques may well enable Japanese companies to overtake U.S. firms and to dominate what many expect to be an eventual several hundred billion dollar world market.

Solar central receiver technologies are being pursued actively by Japan and the European Common Market countries. Of six central receiver generating stations in the world, two are in operation in Spain, and one each is in operation in the United States, France, Italy, and Japan. While Solar One in California uses a water/steam cycle, Spain is demonstrating the liquid sodium working-fluid concept, while others use the molten salt concept.

Wind energy is also being pursued by several European countries. Of particular note is the wind turbine development program in Sweden, where a 3 MW demonstration project is being constructed by an international consortium of companies. If it is demonstrated to be sound, the technology will be ready for export or for cross licensing. This could directly affect U.S. competitiveness, especially if the MOD-5 turbine design is not pursued.

The international leader in the development of solar salt pond technology is an Israeli firm which has constructed and operated small salt ponds at the

Dead Sea. Demonstration of this technology is hampered by cost and environmental considerations. While the Israelis are proceeding with the needed scaled-up demonstration project, a similar effort in the United States remains uncertain.

This potential gain by foreign competitors must be recognised as a factor in the development of U.S. energy security and in R&D planning. A related issue is the appropriate Federal R&D support for U.S. solar technologies which are intended primarily for export. The European and Japanese solar programs seem heavily tilted towards export markets, especially solar photovoltaic devices in consumer goods. The Panel believes that the Federal Government should establish a rigorous U.S. posture toward solar technology exports to provide a context for actions and for effective Government-industry relations in this area. If the United States does not maintain its R&D activities in materials and component development and achieve cost reductions, it is likely to face quick erosion of its technological lead in the world.

XI. FINDINGS AND RECOMMENDATIONS

The Panel's findings and recommendations are summarized below. These are presented relative to the major elements of the Panel's charge from DOE given in the introduction.

A. State of the Solar Industry

- Solar energy has made significant progress in the last 10 years.

  The accomplishments of the solar industry over the past decade are impressive. The Panel is optimistic about the commercial future of numerous solar technologies if the Federal and private sector relationships are handled with care.

- Solar energy technologies represent a series of highly promising energy options for the U.S.

  Overall, the solar technologies--many of which have been important at the regional level for many years--represent a series of highly promising, energy options for the United States, offering both demonstrated technical feasibility and a secure, long-term, renewable resource base to draw from. Solar technologies are becoming increasingly competitive in the marketplace. The promise of solar energy becomes even more important with the realization that the current oil surplus is transitory. The U.S. dependence on finite, interruptible, and environmentally questionable fossil fuels constitutes a vulnerability in the health of our economy and a potential threat to national security.

- The U.S. solar industry is in a precarious position.

  Except for the conventional biomass industry, which operates in a well-defined marketplace, most of the growing solar industry is in a precarious competitive position relative to conventional energy technologies and older industries which are firmly established. In addition to the technical risks associated with relatively new technologies, the emerging solar industry has to contend (together with all other industries) with today's economic conditions, including high cost of capital and fluctuating energy demand and prices, as well as with uncertainty about Federal tax and regulatory policies--all of which serve to increase the perception of risk and to discourage investment.

B. Transfer of Federal R&D to Private Sector Sponsorship

- For some technologies, the private sector is ready to undertake commercialization; for others, the Administration's policy will result in a slowdown or termination.

Some solar technologies are ready for commercialization, and, for them, heavy DOE R&D support is not needed. But for others, the expectation that private industry alone will finance the demonstration of near-commercial, large scale technologies that otherwise are ready for commercial operation is not always realistic. In the shorter term, the withdrawal of all Government support for demonstration and commercialization of near-commercial, cost-competitive solar technologies undoubtedly would slow the rate at which these technologies will be introduced into the marketplace. Still other technologies would be terminated, at least temporarily, without continued Federal support for commercialization.

- The business and residential energy tax credits are essential to the near-term health of the solar industry and should be extended and gradually phased-out.

At a time when direct Federal involvement in commercialization is ending, an appropriate tax policy may be the most important factor to provide the bridge necessary for private sector commercialization to occur. The business energy tax credit, the residential solar energy tax credit, and some provisions of the Economic Recovery Tax Act have been essential to private investment, by balancing subsidies for other energy sources. These tax credits should be continued until 1986 and then gradually phased-out by 1990 to allow industry and the marketplace to adjust. A specific phasedown schedule needs to be set to allow for industrial planning. The R&D tax credit is valuable but cannot take the place of the Business Energy Tax Credit and will not by itself be a major factor in the private sector moving ahead with renewable energy technologies. The the R&D tax credit can be improved by broadening it to include new businesses.

C. Federal and Private Sector Roles

- Support of basic and applied research and development of a solar technology base from fundamental research through engineering development, are important Federal roles.

  Support of basic and applied research and high-risk, potentially high-payoff research and development are important Federal roles. They provide information and knowledge which benefit the country as a whole, but are not of sufficient benefit to any one interest to warrant private investment.

- The Panel concludes that the proper DOE role should be limited largely to supporting technology base activities, including basic and applied research, exploratory and technology development, and vigorous technology transfer efforts such as operating some key test facilities and programs.

- Engineering development programs, such as small scale pilot plants, may be justified in special cases when substantial industry cost sharing is forthcoming.

- Costly new demonstration and commercialization programs funded by the DOE are not justified under current budgetary conditions.

- The importance of technology transfer increases with the increased private sector roles.

  Federal technology transfer must recognize that the solar technologies are considerably spread out along the path from basic research to commercialization, and that technology tranfer must be designed specifically for each technology and industry. Dissemination of documents alone is not effective. Other methods must be employed. Programs should not be abandoned until the transfer is assured. If the Administration's new R&D policy is to be successful, Federal solar programs which produce near-commercial technology should work closely with industry to affect a full transfer of information, technology, and techniques as soon as possible.

- DOE should continue its lead role in resource assessments, testing, assessments of enviromental issues, and continue to cooperate with industry in standards development.

  The DOE role also should include important technology support functions not likely to be conducted by private industry, namely solar energy technology assessments, performance testing of specialized materials and components, test facilities, programs and assistance in developing industry-wide standards, and assessment of environmental issues. These activities reduce risk for investors and improve market acceptability.

- Reduction in the DOE solar budget requires consolidation and restructuring of DOE programs and management style.

  Because of extensive recent reductions in the DOE solar budget, the current budget level may not suffice to support a "critical mass" of scientists and engineers in each of the locations where research and development activities have existed in the past. A consolidation of activities into fewer field offices, national laboratories, and research centers is likely to improve R&D efficiency and reduce management overhead. Moreover, as the DOE role changes to emphasize research and technology development, (as contrasted with large scale demonstration and construction emphasis in the past) a research management structure should be adopted whereby more management authority is vested in fewer lead centers and research centers.

- Continuity in Federal actions is essential to solar R&D.

  Rapid changes and discontinuities in Federal policy and program direction over the last five years have disrupted orderly technical progress and have caused uncertainty and unanticipated costs in the private sector. Continuity, relative stability, and gradual change are critical for research and development. This may be more important than the absolute amount of money in the budget. To stabilize DOE and Laboratory planning and program execution and to foster an expectation of continuity essential for securing private sector commitment, 2-year, rolling appropriations by Congress for solar R&D are urged.

- The utility industry may not make major investments in demonstration or pilot plants because of financial and regulatory constraints.

  The utilities, with some exceptions, do not have the resources to make major investments in demonstration or prototype facilities. Their allowed rates-of-return are not commensurate with the risks involved. Utility efforts, with a few exceptions, are likely to focus on small, end-use projects. The R&D programs of EPRI and GRI have been important to the nation's solar R&D program, but their budgets are also not capable of supporting demonstration or pilot plants.

D. Critical Solar R&D Issues and Objectives

General findings and recommendations regarding each solar technology are summarized below. However, each of the previous chapters contain more specific information on promising areas of solar R&D that may also be of interest to the reader.

1. Solar Related Research

- Basic energy research provides an understanding of the physical phenomena that make new technology possible and should be supported by the Assistant Secretary, Conservation and Renewable Energy.

  As the Federal role in research becomes more prominent, AS/CE programs should identify and support basic and applied research which directly supports a technology area in addition to existing support from, and in close coordination with, Basic Energy Sciences Programs.

- Basic research in photosynthesis and photochemistry is essential to programs in solar photoconversion technology.

  Visible light sensitizers, photosensitive interfaces, photochemistry of CO_2 and water to produce fuels, multistep electronic processes for kinetic inhibition of back reaction, and photodegradation are among research areas that merit DOE R&D funding.

- Basic research in materials, with emphasis on three basic problems--degradation, interfaces and stable synthetic materials with good optical properties--should be vigorously supported.

  Basic research programs should provide the phenomenological understanding to support the next generation of technologies in each of the solar technologies. The Panel has identified the need for new materials, the understanding of degradation mechanisms, and interfaces, as factors currently limiting the development of new technology in a number of technologies, and supports continuing research in each of these areas.

- Education and training of personnel in the solar technologies should be supported.

  Advances in areas such as photovoltaics and solar photochemistry hinge on the supply of educated scientists and engineers who will direct their talents to solar technologies. These people must have the opportunity for a strong education in the related scientific and engineering disciplines. The DOE should take a leading role in supporting basic research and education in solar-related areas at universities.

2. Photovoltaics (PV)

- PV research is a near-ideal candidate for DOE support.

  PV technologies have a demonstrated track record of substantial improvements. Because of its modular nature, which is conducive to small-scale use, PV offers near-term and long-term potential for commercialization, with eventual high-payoff in both utility, industrial and residential applications. However, increasing international competition from Japan and Europe could undermine U.S. technological leadership. Since the potential payoff remains high. DOE should continue to support selected PV development.

- Highest payoff is expected from improvements in compound semiconductor and silicon thin films.

  Highest payoff is expected from advanced research and development of compound semiconductor and silicon thin film solar cells. Crystalline thin films hold out most promise for high efficiency. In addition to Federal R&D for single-junction, crystalline, thin film cells, other promising areas include advanced multi-junction concepts and amorphous silicon. Technology development of high purity/low cost silicon material, concentrator concepts, advanced sheet formation, high efficiency single and polycrystalline silicon solar cells and module endurance is also necessary.

- DOE support is needed for an innovative concepts R&D program.

  A specific innovative concepts program similar to that previously initiated by DOE is recommended. This program can be used to explore PV research to advanced thinking on electrolytic cells, polymers and new materials which have the potential for major breakthroughs.

- DOE support for the 1 MWe PV Sacramento Municipal Utility District demonstration project should be discontinued.

  Consistent with cancellation of DOE support for other demonstration projects, DOE support for this demonstration project is deemed inappropriate because current economics make the expectation of large scale commercialization unrealistic.

3. Solar Thermal

- Solar thermal technologies are rapidly reaching commercial status.

  Parabolic troughs are commercially available. A 10 MWe central receiver pilot plant began producing power in April. For both, only a testing program to acquire technical performance and cost data should be Federally supported.

- Central Receivers

  The paramount requirement of the DOE solar thermal central receiver program over the coming years is to ensure that the Solar One experiment is carried through to a logical and thoroughly understood conclusion. In addition, the DOE could cost share with industry on programs which will provide advanced receiver and thermal storage concepts.

- Parabolic dishes

  The DOE should increase emphasis within the solar thermal program to the parabolic dish technology development because of its potentially higher efficiencies and lower costs. Future component research should concentrate on areas that will either significantly improve known efficiencies, extend the useful life, or reduce the capital and operating costs of the modules. Two or three dish/engine module experiments should be evaluated for DOE cost-sharing support.

- Parabolic Troughs

  The parabolic trough technology is ready for commercialization by industry and requires only a low order of continued Federal support in materials research (including environmental testing) and operational testing of key demonstration projects to complete the technology transfer process.

- Technology Base R&D

  DOE programs in basic and applied research related to solar thermal R&D need a much sharper focus with increased funding for advanced technology base development to support the next generation of solar thermal systems: advanced materials with good optical, thermal, and structural properties; advanced, low-cost structures, and advanced processes should be examined.

- Hemispherical bowls

  The Panel recommends discontinuing the hemispherical bowl program becaus of a low average collection efficiency and the thermal losses inherent in the transport of thermal energy over long distances.

- Solar Ponds

  Solar pond technology for both heat and electricity production is still in the developmental stage. In view of foreign leadership in solar ponds, the Panel recommends the maintenance of only a small technical effort to monitor progress in this field. Some exploratory research would be warranted if funds permit.

4. Wind

- MW-sized wind machines are rapidly nearing commercialization.

  The Panel recommends a continuation of DOE support for testing, data gathering, analysis, and publication on the three MOD 2 machines at Goldendale, Washington. Such operational testing should provide data needed to complete transfer of the technology to industry and aid in design of more advanced machines.

- A small wind machine industry now exists. No new Federal involvement is required.

  The Panel recommends phasing out Federal support for small wind demonstration projects by 1985. However, Federally maintained testing facilities should be continued, contingent upon industry use on a full cost recovery basis, to provide industry with a capability not otherwise affordable by individual small businesses.

- Some research and analytical areas remain significant and require continued DOE support.

  While no major breakthroughs are expected, wind characterization, complex structural response, fatigue, wake interaction, noise generation, TV interference, and environmental impacts remain important areas for continued DOE supported R&D.

If, but only if, an overall solar budget continues at the FY 82 level, the Panel recommends a completion of the cost-shared MOD-5 development program, with DOE funds supporting detailed design and testing of two machines, and private companies funding all hardware, construction, and installation. However, the Panel assigns a lower priority to DOE funding of the MOD-5 program.

5. <u>OTEC</u>

- <u>DOE funds should support the 40 MW preliminary design.</u>

  Detailed design and construction should be funded by non-Federal interests; however, DOE involvement in Phases I and II design should be completed. No further demonstrations should be funded by DOE.

- <u>DOE should continue to support critical R&D activities only.</u>

  A modest DOE-supported technology base effort should be continued in support of private efforts including materials for OTEC components, such as the shore and shelf cold water pipe, heat exchanger, and similar activities, as well as for resource and environmental assessments. Such activities have the potential of reducing construction costs and risks considerably.

6. <u>Biomass</u>

- <u>Current DOE program requires sharper focus.</u>

  There is an urgent need for implementation of a new comprehensive R&D framework for the nation's biomass energy R&D program, one that sorts out objectives, priorities and responsibilities. DOE organization should reflect this new framework.

- <u>Need for basic research in expanding both the resource and, secondarily, the technology base</u>.

  The DOE should conduct basic research in expanding the resource base of both terrestrial and aquatic plants through plant species screening and selection, cataloging of plant components to identify potentially valuable chemicals, plant-type collection, insect and disease management, agronomic studies, and basic research in photosynthesis, photochemistry, electrochemistry, metabolism, and other fundamental aspects of plant physiology.

  Secondarily, DOE programs in expanding the technology base should include basic research in biological and thermochemical conversion of biomass, especially lignocellulosic materials from forests. Increased consideration should be given to the development of chemical products which may have a higher value than fuels, as well as the use of hydrogen as a co-feedstock with wood.

- <u>Program emphasis should be on resource enhancement and, secondarily, on conversion technologies</u>.

  The Federal Government should continue its lead role in resource assessment, especially of forest biomass, assessments of other biomass production and available feedstocks, including unused wastes, and other basic data collection activities. Priorities for research in conversion technologies include biological and thermochemical gasification, liquefaction, and chemical conversion of lignocellulosic materials. Such priorities should also be based on the most urgent national energy need such as that for liquid and gaseous fuels.

- <u>Environmental aspects of biomass are significant</u>.

  Biomass energy faces a number of serious environmental and social issues including nutrient loss, soil erosion, water use, water quality degradation, air pollution, introduction of exotic plant species, loss of fish and wildlife habitat, and competition with food and fiber production. Continued environmental research and effective management system needs to be devised for biomass production to prevent environmental degradation and to protect land productivity.

7. Buildings Solar Energy Research

- Research and development leading to improved energy performance in buildings should be given higher priority.

  The Panel was impressed by the potential high-payoff of improving the energy performance of over 80 million existing residential and commercial buildings, as well as the potential for improving performance of new buildings. It assigned a higher overall priority to this area of DOE solar R&D.

- Current DOE building performance tests should be completed and documented.

  Extensive tests mandated by the Solar Heating and Cooling Demonstration Act of 1974 contain valuable performance data. They should be completed and documented by DOE.

- Establish a Buildings Solar Energy Research Program within DOE.

  The Panel recommends that DOE establish a buildings solar energy research program that combines all DOE research and development on solar energy and conversation in buildings. Existing active, passive and conservation programs should be continued in this new organization.

- <u>Major research areas remain appropriate for continued Federal R&D funding</u>.

  Some major gaps as well as the potential for new technology exist in spite of a very old set of needs for comfortable, well-lit, affordable dwellings. New materials with selective thermal and structural properties for buildings, new systems for heating and cooling, and a better understanding of heat and mass transfer in buildings, hold promise to reduce the cost of energy in new and existing buildings. Federal R&D funding for building R&D should be continued.

- <u>DOE should initiate discussions leading to the establishment of an industry funded Buildings Energy Research Institute</u>.

  An industry funded buildings energy institute is needed to provide a large but otherwise fragmented buildings and suppliers industry with the capability for research and development, and to develop a much needed link between DOE, other related Federal programs, and industry.

- <u>Document DOE program results for effective communication</u>.

  A special effort should be made to document DOE results in such language, and to use British units of measurement, so as to facilitate their use by the diverse buildings trade industries.

APPENDIX A

SOLAR R&D PANEL MEMBERSHIP

SOLAR R&D PANEL
ENERGY RESEARCH ADVISORY BOARD

*Victoria Tschinkel (Panel Chairman)
Secretary
Department of Environmental Regulation
State of Florida
Tallahassee, FL

Mr. Donald C. Berkey
Vice President and General Manager (Retired)
General Electric Company
Stamford, CT

Dr. Edward Blum
Vice President and Executive Director
Alternative Energy Financing Group
Merrill Lynch White Weld Capital Markets Group
Washington, D.C.

*Dr. Melvin Calvin
Professor of Chemistry
Department of Chemistry
University of California
Berkeley, CA

*Dr. Dayton Clewell
Senior Vice President (Retired)
Mobile Oil Corporation
Darien, CT

*Mr. Norman Hackerman
President
Rice University
Houston, TX

*Dr. Charles J. Hitch
President Emeritus
University of California
Berkeley, CA

Mr. Roger Little
President
Spire Corporation
Bedford, MA

Dr. Lawrence Papay
Vice President, Advanced Engineering
Southern California Edison Company
Rosemead, CA

*Dr. David Pimentel (Panel Vice Chairman)
Professor
Department of Entomology & Section on Ecology and Systematics
Cornell University

**Mr. Louis H. Roddis
Consulting Engineer
Charleston, SC

Mr. Byron Washom
President
ADVANCO Corporation
El Segundo, CA

Dr. Mark S. Wrighton
Department of Chemistry
Massachusetts Institute of Technology
Cambridge, MA

Professor John Yellott
Arizona State University
College of Architecture
Tempe, AZ

STAFF

William L. Woodard
Executive Secretary
Solar R&D Panel
Energy Research Advisory Board
Department of Energy
Forrestal Building, ER-6
Washington, D.C. 20585
(202) 252-8933

Dr. Meir Carasso
Senior Advisor, Solar R&D Panel
SERI
Golden, CO

Dr. Stephen I. Kaplan
Technical Advisor
Solar R&D Panel
Oak Ridge National Laboratory
Oak Ridge, TN

*ERAB Members
**ERAB Chairman and _ex officio_ member of Panel

APPENDIX B

ENERGY RESEARCH ADVISORY BOARD MEMBERSHIP

ENERGY RESEARCH ADVISORY BOARD

<u>Chairman</u>

Louis H. Roddis, Jr.
Charleston, SC

<u>Vice Chairman</u>

Ivan L. Bennett
Professor of Medicine
New York University Medical Center
New York, NY

MEMBERSHIP

Herman R. Branson
President
Lincoln University
Lincoln University, PA

Solomon J. Buchsbaum
Executive Vice President
Customer Systems
Bell Laboratories
Holmdel, NJ

Melvin Calvin
Professor of Chemistry
University of California
Berkeley, CA

Dayton Clewell
Senior Vice President (Retired)
Mobil Oil Corporation
Darien, CT

Thomas B. Cochran
Senior Staff Scientist
Natural Resources Defense Council
Washington, DC

Floyd L. Culler, Jr.
President
Electric Power Research Institute
Palo Alto, CA

Martin A. Elliott
Consultant to
Texas Eastern Transmission Corporation
Houston, TX

James C. Fletcher
Professor of Technology and
Energy Resources at the
University of Pittsburgh

John S. Foster, Jr.
Vice President for
Science and Technology
TRW, Inc.
Cleveland, OH

Norman Hackerman
President
Rice University
Houston, TX

Charles J. Hitch
President Emeritus
University of California
Berkeley, CA

Hans H. Landsberg
Senior Fellow
Resources for the Future
Washington, DC

William S. Lee
President and Chief Operating
Officer
Duke Power Company
Charlotte, NC

William T. McCormick
President
American Natural Resources Company
Detroit, MI

ENERGY RESEARCH ADVISORY BOARD
MEMBERSHIP
(Continued)

David Pimentel
Professor
Department of Entomology and
Section on Ecology and Systematics
Cornell University
Ithaca, NY

Eric H. Reichl
President (Retired)
Conoco Coal Development
Greenwich, CT

Roland W. Schmitt
Vice President
Corporate Research and Development
General Electric Company
Schenectady, NY

John W. Simpson
Consultant to
International Energy Associates, Ltd.

Grant P. Thompson
Senior Associate
The Conservation Foundation
Washington, DC

Victoria J. Tschinkel
Secretary
Department of Environmental
Regulation
Tallahassee, FL

Staff Contacts

Thomas J. Kuehn, Executive Director
William L. Woodard
Mary Gant
Joan Snodderly
Energy Research Advisory Board
Department of Energy
Forrestal Building, ER-6
1000 Independence Avenue, S. W.
Washington, DC 20585

APPENDIX C

LETTER FROM REPRESENTATIVE FUQUA
AND
DOE RESPONSE

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
SUITE 2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, D.C. 20515
(202) 225-6371

December 10, 1981

Hon. W. Kenneth Davis
Deputy Secretary
Department of Energy
Washington, D. C. 20585

Dear Mr. Davis:

Recently I met with Lou Roddis, the chairman of the Energy Research Advisory Board, to discuss ERAB's energy RD&D priorities report and other related issues. I was pleased to learn that ERAB has initiated two new studies on program areas significantly affected by the FY 1982 budget reductions - the national laboratories and energy conservation RD&D. However, it struck me at the time that one additional area that has also been significantly affected and is of special interest to the Committee is the solar energy research, development and demonstration program.

As you know, the President's proposed FY 1982 budget reduced funding for solar energy from $576 million to $193 million and proposed termination of a number of technology development projects of special interest to our Committee, including the OTEC pilot plant, MOD-5 wind turbine program, low cost silicon array project and solar thermal repowering. Many of these activities have been restored in the Energy and Water Development Appropriations Act. However, the budget is still drastically reduced from 1981 levels and this raises a number of issues which have not yet been fully resolved. Specifically:

1. What activities will industry be able to pick up and which ones will terminate as a result of the FY 1982 budget reductions? The FY 1982 budget justifications contained assurances that the private sector would carry out the development and demonstration activities formerly undertaken by the DOE solar program. Yet to date, no study has been done by DOE to determine whether this in fact will be the case and to propose alternatives if the private sector cannot take on the terminated activities.

2. How can the transition from the large solar budgets of the previous years to the decreased budgets of the current Administration be carried out in a way that salvages the maximum

amount of useful information and material from the Federal investment to date? The FY 1982 budget reductions were in many cases so drastic and abrupt that an orderly termination of Federal involvement in the programs may be impossible. In some areas such as that of the MOD-5 wind turbine, failure to make a very small additional Federal investment could prevent a multi-hundred million dollar RD&D effort from achieving tangible results. It does not appear that adequate care has been taken at DOE to insure that the fruits of more than $2 billion worth of RD&D are not irretrievably lost.

3. What is the proper long term Federal role with respect to solar energy? The Department claims that its only role in solar will be "long term, high risk research and development" but this term has not been well defined and is not applied consistently across solar technologies. For example, OTEC R&D was proposed for complete termination while passive demonstrations and biomass conversion systems are still supported. Moreover, it is not clear that long term R&D is the best way for DOE to spend its limited RD&D dollars if it is to assist the private sector in developing solar technologies. Often small cost-shared demonstrations, information dissemination, field testing and assistance in promulgating voluntary standards are more important to industry.

Because of the great uncertainties and still unresolved questions raised by the Administration's FY 1982 solar budget, I respectfully request that you ask the Energy Research Advisory Board to conduct a study of solar RD&D. I suggest that the study would examine priorities and funding levels for the Department of Energy's solar and technology programs and should address the general question of the proper continuing federal role in solar RD&D.

Sincerely,

DON FUQUA
Chairman

DF:Fwm

Department of Energy
Washington, D.C. 20585

February 8, 1982

Honorable Don Fuqua
Chairman, Committee on Science
and Technology
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

In your letter of December 10, 1981, you ask that the Energy Research Advisory Board (ERAB) conduct a study of solar R&D. In support of this request you raise several questions dealing with industry's ability to assume leadership for continued solar development, the need for a cost effective transition from Federal private efforts, and the long-term Federal role in solar energy research and development.

The Department of Energy (DOE) solar energy program has done an outstanding job in sorting among the many energy technology options and developing those showing the most economic and technical promise. It is appropriate that continued development of such efforts transfer to private industry, leaving DOE to concentrate its support on long-range research and development. In the transfer process DOE's objective is to create conditions that will insure that the Federal program "know-how" moves in a way that facilitates private sector leadership. In this regard, the ERAB is in a unique position to offer advice aimed at maximizing both private and Federal resources.

Accordingly, I will forward a copy of your letter to the chairman of the Energy Research Advisory Board with a request that he initiate a review of the solar energy program along the lines outlined above.

Sincerely,

W Kenneth Davis

W. Kenneth Davis
Deputy Secretary

APPENDIX D

LETTER FROM W. KENNETH DAVIS DEPUTY SECRETARY, DOE ESTABLISHING TERMS OF REFERENCE

Department of Energy
Washington, D.C. 20585
March 16, 1982

March 15, 1982

Mr. Louis H. Roddis, Jr.
Chairman
Energy Research Advisory Board
110 Broad Street
Charleston, SC 29401

Dear Lou,

In recent years, the Department of Energy (DOE) has considered many solar technology options and supported the development of those showing the most promise. Many of these technologies have reached a point that continued development can be done by private industry if they appear to be economical, leaving DOE to concentrate its support on research. It is DOE's objective to pass on to interested industry the Federal program "know-how" derived from our former activities.

Concern has been expressed in Congress that reductions in the solar budget have been so abrupt as to limit the ability of the private sector to effect an orderly transfer of technology. In particular, the Chairman of the House Science and Technology Committee has asked that this issue be examined. I enclose a copy of the Chairman's letter to me and my reply.

I realize that the Board has already addressed the question of priorities among programs in its R&D priorities report. However, a more definitive examination of the appropriate Federal role in solar R&D is needed. In each of the technologies, what specific research objectives should we support? Therefore, I would like the Energy Research Advisory Board to undertake a study of the solar energy program that would help the Department define the most effective Federal program given the limited resources that will probably be available.

This assessment should be in the context of the Administration's policy to use Federal funds for R&D that is long-term, high-risk and high-payoff and would not be undertaken by the private sector. In view of these criteria and the very limited financial resources likely to be available during the next several years, the Board should address the appropriate Federal roles with respect to each solar technology, and consider what mechanisms may be needed to ensure an efficient transition of solar technology developed by Government to the private sector. The Board should also address the ability and incentive of industry to assume leadership for continued solar development in the respective solar technologies. This analysis should help ensure that future Federal investments will provide the long-term scientific base needed for a healthy and competitive national effort.

I am sure that the Assistant Secretary for Conservation and Renewable Energy will be glad to assist the Board in carrying out this study.

In view of the interest in this program, I would appreciate it if the Board would submit its report by mid-September or before. I appreciate the Board's willingness to advise the Department in this important area.

Sincerely,

Ken

Enclosures

APPENDIX E

SOLAR PANEL MEETINGS AND AGENDAS

SOLAR R&D PANEL
ENERGY RESEARCH ADVISORY BOARD

May 12, 1982
Room 4A-110, Forrestal Building
(Open to the Public)

9:00 a.m.	Introduction and Organization Matters	V. Tschinkel Chairman, Solar R&D Panel
9:05 a.m.	Welcoming Remarks	L. Roddis Chairman, ERAB
9:15 a.m.	Administrative Items	T. Kuehn Executive Director, ERAB
9:30 a.m.	Nature of Charge and Report Structure Future Meeting Schedule	V. Tschinkel
10:15 a.m.	Solar R&D Panel Briefings - Introduction	R. San Martin Deputy Asst. Secretary DOE/Solar Energy
10:30 a.m.	Photochemistry and Basic Research	R. Kropschot, DOE
11:00 a.m.	Photovoltaics	L. Barrett, DOE
11:30 a.m.	Biomass, MSW, and Alcohol Fuels	R. Benson, DOE
12:00 Noon	Active and Passive	F. Morse, DOE
12:30 p.m.	Lunch	
1:30 p.m.	Program Briefings (Continued) Solar Thermal	G. Braun, DOE
1:50 p.m.	Wind	L. Divone, DOE
2:10 p.m.	Ocean Thermal	W. Richards, DOE
2:30 p.m.	Roundtable Panel Discussion o Solar R&D Problem Areas and Issues o Report Structure o Information and Staff Study Requirements o Items for Future Meetings	Solar R&D Panel Members
4:00 p.m.	Adjourn	

SOLAR R&D PANEL
ENERGY RESEARCH ADVISORY BOARD
MEETING ON SOLAR RESEARCH AND INDUSTRY

June 14, 1982
Room 4A-110, Forrestal Building
(Open to the Public)

8:30 a.m.	Opening Remarks	V. Tschinkel Chairman, Solar R&D Panel
9:30 a.m.	Wind, OTEC	A. Jackson, Hamilton Standard
		J. Lowe, Boeing Engineering Construction
		F. Naef, Lockheed Corporation
		F. Whitson, Bendix Corporation
10:30 a.m.	Thermal/Active/ Passive	M. Davis, Sun Belt Energy Corporation
		R. Johnson, NAHB Research Foundation, Inc.
		D. Schine, Sanders Associates
		T. Springer, Rockwell International
		J. Weiss, Acurex Solar Corporation
12:30 p.m.	Lunch	
1:00 p.m.	Photovoltaics	E. Berman, Arco Solar, Inc.
		J. Evans, Jet Propulsion Laboratory
		T.W. Russell, U. Delaware
		V. Weekman, Mobil Tyco Solar Energy Corporation
2:30 p.m.	Biomass	W. Lawhon, International Spike
		R. Katzen, Raphael Katzen Associates Inc.
3:30 p.m.	Round Table Discussion	Solar R&D Panel and Spokesmen
4:00 p.m.	Adjourn	

SOLAR R&D PANEL
ENERGY RESEARCH ADVISORY BOARD
MEETING ON BASIC AND APPLIED RESEARCH

July 1 and 2, 1982
Solar Energy Research Institute
(Open to the Public)

July 1, 1982

9:00 a.m.	Opening Remarks	V. Tschinkel Chairman, Solar R&D Panel
9:10 a.m.	Welcoming Remarks	H. Hubbard Director, SERI
9:20 a.m.	Introduction	V. Tschinkel Solar R&D Panel
9:30 a.m.	PV Research Overview	J. Stone, SERI
	Amorphous Silicon	D. Redfield, RCA Laboratories
	Thin Films	J. Meakin, U. Delaware
	High Efficiency Cells	J. Fan, MIT, Lincoln Laboratories
	Polycrystalline Silicone	A. Lesk, Solavolt International
	Solid State Physics	M. Wolf, U. Pennsylvania
	PV Subpanel Progress Report	R. Little, Solar R&D Panel
12:30 p.m.	Lunch	
1:30 p.m.	Thermal, Active/Passive Research Overview	B. Butler, SERI
	Materials Sciences	B. Seraphin, U. Arizona
	Thermal Sciences	F. Kreiph, SERI
	Chemical Sciences	R. Cassanova, Georgia Institute of Technology
	Engineering Sciences	W. Schimmel, Sandia
	Basic Research	L. Murr, Oregon Graduate Center
	Thermal Subpanel Progress Report	B. Washom, Solar R&D Panel
	Active/Passive Sub-Panel Progress Report	J. Yellott, D. Clewell, Solar R&D Panel
4:00 p.m.	Adjourn	

<u>July 2, 1982</u>

8:30 a.m.	Advanced BIotechnology Overview	C. Smith, SERI
	Resources Oriented Research	E. Lipinsky, Battelle
	Products/Need Oriented Research	C. Hinman, Diamond Shamrock, Inc.
	Plant Research	R. Adams, Plant Resources Institute
	Genetics, Microbiology, Biochemistry	D. Wong, MIT
	Biochemical Engineering	H. Bungay, Rensselaer Institute
	Thermochemistry	T. Milne, SERI
	Photoconversion	A. Nozik, SERI
	Biomass Subpanel Progress Report	V. Tschinkel, Solar R&D Panel
11:00 a.m.	Wind Energy Research	R. Thomas, NASA/Lewis
	Wind Subpanel Progress Report	D. Berkey, Solar R&D Panel
11:30 a.m.	OTEC Energy Research	W. Avery, Johns Hopkins University
12:00 Noon	Lunch	
1:00 p.m.	BER Subpanel Progress Report	M. Wrighton, Solar R&D Panel
1:30 p.m.	Overview Progress Report	E. Blum, Solar R&D Panel
2:00 p.m.	Discussion and Summary	V. Tschinkel, Solar R&D Panel
3:00	Adjourn	

SOLAR R&D PANEL
ENERGY RESEARCH ADVISORY BOARD
MEETING ON TECHNOLOGY AND ENGINEERING DEVELOPMENT

July 13 and 14, 1982
Sandia, Albuquerque, New Mexico
(Open to the Public)

July 13, 1982

8:30 a.m.	Opening Remarks	V. Tschinkel Chairman, Solar R&D Panel
8:40 a.m.	Welcoming Remarks	E. Beckner, Energy Programs, Sandia
8:50 a.m.	Overview	V. Tschinkel Solar R&D Panel
9:00 a.m.	PV Development Overview	J. Evans, Jet Propulsion Lab
	Economics & Timing	J. Smith, Jet Propulsion Lab
	Flat Plate Collector T.D.	W. Callaghan, Jet Propulsion Lab
	Concentrator Collector T.D.	E. Boes, Sandia
	Systems R&D	G. Jones, Sandia
	BOS Component T.D and Systems Experiments	E. Burgess, Sandia
11:15 a.m.	Wind	T. Healy, Rocky Flats Wind Plant
12:00 Noon	Lunch	
1:00 p.m.	Heating/Cooling Overview	E. Mazria, Mazria & Schriff, Assoc.
	Active Heating & Cooling Systems	F. Bridgers, Bridgers & Paxton
	Passive Heating Systems	E. Mazria, Mazria & Schriff, Assoc.
	Passive Cooling Systems	A. Bowen, U. Miami
	Building Integrated Design	D. Balcomb, LANL
2:30 p.m.	Thermal Systems Overview	D. Schueler, Sandia
	Central Receiver	A. Skinrood, Sandia, Livermore
	Dishes	V. Truscell, Jet Propulsion Lab
	Troughs	J. Banas, Sandia
	Ponds	R. French, Jet Propulsion Lab
4:00 p.m.	Adjourn	

July 14, 1982

8:30 a.m.	Panel Deliberations	V. Tschinkel, Chairman, Solar R&D Panel
10:30 a.m.	Energy Biotechnology Overview Silviculture Environmental Constraints Aquatic/Biomass Applications On-Farm Biomass Applications	P. Benson, Gas Research Institute D. Dawson, Consultant J. McBrayer, ORNL L. Raymond, SERI J. Butler, USDA
12:30 p.m.	Lunch	
1:00 p.m.	OTEC Technology	A. Butler, TRW, Inc.
1:30 p.m.	Financial Overview	E. Blum, Solar R&D Panel
2:30 p.m.	Federal/State Interaction	G. Ventre, FL Solar Eng. Center J. Veigel, NC Alt. Eng. Corp.
3:00 p.m.	Summary & Panel Discussion	V. Tschinkel, Chairman, Solar R&D Panel
4:00 p.m.	Adjourn	

SOLAR R&D PANEL
ENERGY RESEARCH ADVISORY BOARD

August 1-2, 1982

Room 4A-110, Forrestal Building
(Open to the Public)

August 2, 1982

9:00 a.m.	Opening Remarks and Reading of Draft Report	Chairman/Panel Members
10:00 a.m.	Overview of Solar Industry	E. Blum/Panel Members
11:00 a.m.	Wind	D. Berkey/Panel Members
12:00 Noon	Lunch	
1:00 p.m.	Photovoltaics	R. Little/Panel Members
2:30 p.m.	Thermal	B. Washom/Panel Members
4:00 p.m.	Public Comments & Panel Discussion	Members of Public/Panel
5:00 p.m.	Adjourn	

August 3, 1982

8:30 a.m.	Eneryg Biotechology	D. Pimentel/Panel Members
10:00 a.m.	Basic Research	M. Wrighton/Panel Members
11:00 a.m.	Active/Passive	D. Clewell/Panel Members
12:00 Noon	Lunch	
1:00 p.m.	OTEC	D. Berkey/Panel Members
1:30 p.m.	Executive Summary	V. Tschinkel/Panel Members
3:30 p.m.	Public Comments	Members of Public/Panel
4:00 p.m.	Adjourn	

APPENDIX F

STAFF STUDIES IN SUPPORT OF SOLAR R&D PANEL

STAFF STUDIES IN SUPPORT OF SOLAR R&D PANEL

1. Solar Material From the DOE Sunset Review Documents

2. A Summary of Solar Energy Technologies in Foreign Governments and Industries

3. Non-DOE Government Solar Programs: Current Activities and Trends

4. Solar Energy Technologies: Market Estimates and Federal R&D Payoff

5. A Compendium of Legislation Relating to Solar Energy, 93rd Through 97th Congresses

6. Background Information on Industry Status
   - o Biomass
   - o Alcohol Fuels
   - o Municipal Waste Energy Systems
   - o Wind Energy Conservation Systems
   - o Passive Systems and Designs
   - o Solar Thermal Energy Systems
   - o Photovoltaic Energy Systems
   - o Active Heating and Cooling Systems
   - o Ocean Thermal Energy Conversion

7. Solar Energy Technology Resource Book
   - o Ocean Thermal Energy Conversion
   - o Solar Thermal Energy Conversion
   - o Wind Energy Conversion
   - o Photovoltaics