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Annual Review of Solar Energy

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Program Evaluation Branch, SERI

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PREFACE

The Annual Review of Solar Energy is a major product of the activities of the Program Evaluation Branch of SERI. The Branch's general mission is to provide analysis and assessment of a broad range of existing and past solar energy activities to compare the effectiveness of different courses of action. The Branch investigates the past development and present status of solar energy programs, including programs of Federal, state, regional, and local public agencies; international activities relevant to United States interests in solar energy; and solar energy activities of not-for-profit organizations, business organizations, and individuals. This information supports the primary function of program evaluation: to assess the future impacts (intended and unintended) of existing and alternative programs in order to inform decisions about future program development. The specific objectives of this activity are:

- to affect decisions about initiating, terminating, or making major changes in program design or funding;
- to identify specific performance problems, including the need for adjustment in resources or revisions in management and planning procedures;
- to improve public awareness and understanding of solar energy activities and solar program options.

In support of the above objectives, the Annual Review of Solar Energy is intended to provide a comprehensive overview of the United States solar energy effort, and to evaluate its effectiveness in responding to long-term national goals and needs. The Review's intended audience includes all who have a serious interest in solar energy development: Federal energy officials, members of Congress, state and local energy decision-makers, consumer and industry interests, and concerned private citizens. Because of the early stage of SERI's development, this first Review is predominantly descriptive rather than evaluative. Future volumes of the Review will be far more analytical and critical, focusing more on specific issues, trends, technological problems, and social options relevant to the future development of solar energy as a resource for serving human needs. Although the Review will continue to attempt a broad overview of the national effort in solar energy development, the emphasis on particular problems, issues, and technologies will shift from year to year.

The first Review is not sufficiently analytical to support powerful conclusions about the present and future status of solar energy development. Nevertheless, the work required to prepare this volume has led to some general impressions.

First, the outstanding characteristic of current solar energy development is diversity. No single national solar energy "program" exists; rather, there are a great number and variety of solar energy programs, projects, and policies aimed at increasing the nation's use of solar energy resources. At the Federal level, several departments and agencies (in addition to the new Department of Energy) have active interests in solar energy. State, regional, and local agencies also are developing their own solar energy policies and programs—in some cases these are being pursued more aggressively than Federal efforts. Private enterprise is investing substantially in solar energy R&D, and already has made some solar technologies a commercial reality. And the American people, acting both individually and through organized groups, are purchasing solar equipment, lobbying for legislation to promote solar development, and even designing and building their own solar systems.

In addition to this multiplicity of actors and activities in the United States solar effort, there are a great variety of technologies and systems included under the "solar" rubric. While the "solar collector" for space heating seems to symbolize solar technology in the public's mind, there actually are dozens of technical systems which can or potentially may make practical use of the sun's energy, as Part II of this Review shows.

A second general impression worth noting is that solar energy clearly is entering a new, dynamic era. Although solar energy is humankind's oldest energy resource, the next century may well see solar energy used more intensively, on a larger scale, and with greater technological sophistication than ever before. There is great uncertainty about the future of solar energy use, resulting in part from the unpredictable nature of technological development, from instability in international, social, and economic relationships, and from disagreements about the limits of existing energy resources. The potential "alternative futures" of American solar energy development span a wide range, from a relatively minor role for solar energy to the possibility of solar being America's primary energy source in the 21st Century. However uncertain the future of solar energy use may be, two important points stand out: (a) solar energy is a significant energy option which is available to serve important human needs in the near future, and (b) solar energy is a major candidate for the basis of the "inexhaustible" energy system which must replace today's conventional energy resources within the next century.

A third observation is that the Federal solar energy research effort is still smaller than that for other energy sources, but has been growing rapidly in recent years. Research on some solar technologies has been highly productive and has led to rapid improvements in technical capability and economic feasibility. As a substantial R&D program has become established, researchers and government decision-makers have become more concerned about the nonhardware aspects of solar energy develpment. Social, political, economic, environmental, behavioral, cultural, and humanistic factors increasingly are being recognized as the major determinants of future solar energy use, and the growing concern for these societal issues will be reflected in coming editions of the Annual Review of Solar Energy.

This volume of the Review is divided into two main parts. The first part provides a general review of national solar energy programs. Chapter 1 is an executive summary of the entire contents of the volume. A brief history of the Federal solar energy program is presented in Chapter 2. The National Energy Plan was the major energy policy event of the past year; Chapter 3 discusses the issues and implications of the NEP that relate to solar energy development. Chapter 4 provides an overview of the present Federal solar energy program, including the activities of several Federal agencies outside the Department of Energy. The national solar energy effort includes many programs and activities in addition to those of the Federal Government. Chapter 5 reviews some of these other solar energy programs; the chapter includes international programs in which the United States has some role, programs of state and local governments, college and university programs, the work of private industry, and individual and small scale activities in solar development. Although not offering a specific prediction of solar energy's future, Chapter 6 discusses some of the major economic, social, environmental, and other forces which will influence the future path of solar energy development. The chapter's intent is to show why the future role of solar energy is highly uncertain and controversial.

The second part of this Review provides a synopsis of the major categories of solar energy technology. Each chapter discusses a particular technology area and includes a basic technological description; a summary of the goals and activities of the Federal R&D program for the technology; significant events and developments of the past year; and a brief overview of problems, uncertainties, and dissenting views. Each chapter was written by an expert on that particular technology. Consequently, the description of Federal programs and discussion of research needs and priorities are not completely consistent from one chapter to another. The purpose here is not to evaluate the total Federal R&D effort but to provide an overview of solar energy R&D activity. Also, the concluding section of each chapter (problems, uncertainties, dissenting views) represents the personal judgment of each author and does not necessarily reflect official views of SERI or DOE.

Three appendices supplement the main text of the Review. Appendix 1 offers a synopsis of major energy events of 1977. Appendix 2 is a glossary of technical terms, abbreviations, and acronyms. Appendix 3 is a table of conversion factors for translating various units of measurement.

The problem of units of measurement warrants a note here. No single set of units is used throughout the field of solar energy R&D. In this text, the units of measurement most common to the literature of a particular application or technology are used. This inconsistency in this volume, although inconvenient, accurately reflects the inconsistencies in the solar energy literature, and makes specific material in this volume compatible with relevant material cited in the notes.

Many people contributed to the completion and production of this first volume of the Annual Review of Solar Energy. The twenty-six contributors listed above were responsible for writing the text of the Review. The six consultants listed provided valuable criticism and guidance. The assistance of Sue Morgan in every phase of work on this volume was invaluable. Vickie Bowler, Judy Daniels, Debbie Miller, and Ken Rourke provided word processing services for the many drafts of this Review which were uniformly timely and efficient. Barbara Glenn's and Bill Gillingham's proofreading and editorial assistance were essential to the successful completion of the task. Jim Miller and Susan Sczepanski had major responsibility for preparation of the Review's graphics. The Review could not have been produced without the enthusiastic support of all these people; for their contributions, the editor and other staff of the Program Evaluation Branch are extremely grateful. We also appreciate the encouragement and support of Dr. Paul Rappaport, Director, Dr. Michael Noland, Deputy Director, and Dr. Melvin Simmons, Assistant Director of SERI.

The Program Evaluation Branch would welcome comments and criticism of this Review, as well as information or suggestions for future volumes of the Annual Review of Solar Energy. Correspondence should be addressed to:

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1. EXECUTIVE SUMMARY

INTRODUCTION

This chapter provides an overview of the body of this report. Highlights of each chapter are included.

PART I — REVIEW OF NATIONAL SOLAR ENERGY PROGRAMS

History of the Federal Solar Program (Chapter 2)

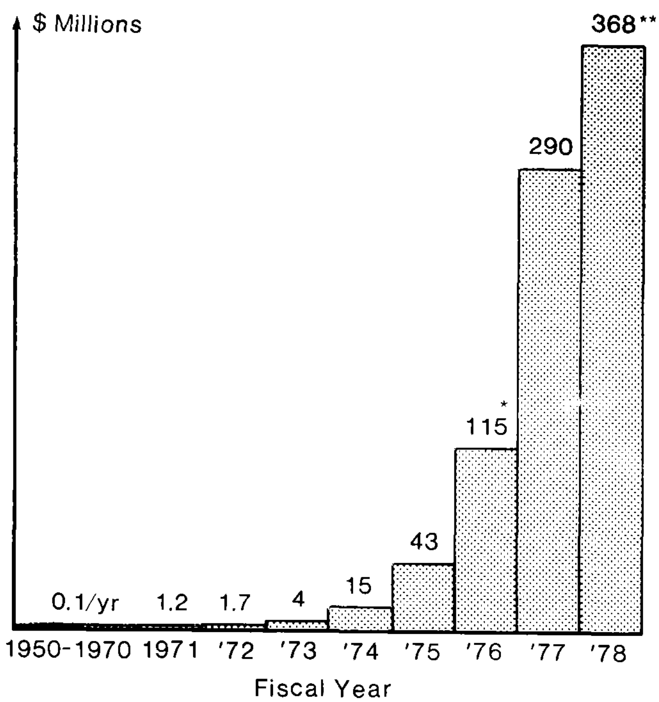
The history of the Federal solar program includes three periods: the early years (the 1950s and 1960s), a period of awakening interest (1971 to 1973), and recent events (1973 to 1977).

The Paley Report (1952) and the Cambel Report (1964) both forecast a major contribution to national energy needs by solar energy. During the 1950s the National Science Foundation (NSF) sponsored research indirectly related to solar energy. By 1961, NSF was funding one or two projects directly concerned with solar energy. Total solar research expenditures through 1970 were only $100,000 annually (Figure 1-1). In spite of an upsurge of popular and scientific interest in solar energy, no solar-related bills survived in Congress.

In FY71 the NSF solar energy budget exceeded $1 million. In 1973 an Atomic Energy Commission panel recommended spending $200 million over five years for solar energy research. From FY71 to FY73 the solar budget totaled more than $4 million. During this period, reports by NSF and NASA and by the Committee on Science and Technology recommended actively developing solar technologies as future energy sources. The Solar Heating and Cooling Demonstration Act of 1973 was the first solar energy bill to be enacted into law. However, during the period of increased Federal interest the prospects for private industry were limited.

Following the Arab oil embargo, the 'Project Independence-Blueprint in Solar Energy' and the NSF document 'National Solar Energy Program' were published. A thousand energy bills were introduced in Congress, including the Solar Energy Research, Development, and Demonstration Act. In 1974 the Federal Energy Administration was created. Also the newly formed Energy Research and Development Administration published ERDA-23

Figure 1-1. SOLAR ENERGY APPROPRIATIONS, 1950-1978



*Funding for the transition quarter between FY 76 and FY 77 $48 million.

**Passed Congress but vetoed by the President because of Clinch River breeder reactor item.

Source: *Solar Energy Legislation Through the 49th Congress*. Washington, D.C.: U.S. Government Printing Office, 1976.

and ERDA-48, outlining Federal solar energy goals. In 1977 the Department of Energy was created, and both the Office of Technology Assessment and the Council on Environmental Quality published assessments of solar energy.

National Energy Plan — Solar Energy Implications (Chapter 3)

President Carter's proposed National Energy Plan (NEP) contains several references to solar energy. These include tax credits to consumers and businesses for installing solar systems, $100 million to add solar equipment to suitable Federal buildings, and a prohibition of utility discrimination against solar users. The NEP also proposes priorities in the solar RD&D budget and calls for the creation of an Office of Small Scale Technology within DOE.

The Congressional conference committees dealing with the NEP had little trouble agreeing on the solar provisions. These include the same business tax credit, a slightly higher consumer tax credit, the same $100 million for Federal buildings, and a weaker utility section (requiring only that state PUCs *consider* nondiscriminatory policies). Congress also would provide $98 million for purchase of photovoltaic cells, loan programs for residential users of solar, and grants for solar installations in schools and hospitals. However, because House leadership has maintained that NEP-related legislation must be passed as a package, and natural gas pricing and oil taxation remain unresolved issues, the solar provisions have not yet been implemented.

Besides the specific solar provisions, the NEP includes energy policy principles which have implications for solar deployment. For example, principle #6 emphasizes the importance of conservation. How will conservation affect solar deployment? Will the "conservation ethic" help turn public consciousness toward solar use? Each of the NEP's ten principles raises important issues for solar energy development.

The NEP also signifies changes in energy policy from that of the previous administration. These changes include higher priorities for solar energy and for conservation, a stronger Federal role, replacement cost pricing (in theory), and a firmer commitment to environmental protection.

The Federal Solar Program (Chapter 4)

The Federal government, largely through the new Department of Energy, is actively promoting the use of solar energy by research, education, information, and demonstration programs. Other Federal agencies are supporting similar programs.

In FY1977 the Department of Housing and Urban Development initiated the fourth of the five cycles of its residential solar heating and cooling demonstration program. The Department of Agriculture was authorized by Congress to establish a model solar farm in each state. The National Center for Appropriate Technology began its small grant program for low-income, appropriate technology projects; many of the projects funded in FY77 were community applications of solar energy.

Dozens of new solar energy-related bills have been introduced in Congress; some may be enacted into law but still await passage of the National Energy Act. Two offices and two councils within the Executive Office of the President are assisting in the development of solar policy and in the management of the Federal solar program.

Among the significant solar energy events in 1977 was the creation of a national Solar Energy Research Institute and four regional solar energy centers.

In spite of rapidly increasing Federal support for solar energy, critics of the Federal program are dissatisfied with the allocation of solar energy funds. Criticism has centered largely on issues of management and organization, the appropriate distribution of effort among solar technologies (Figure 1-2), and the awarding of Government contracts to big business vs. small business firms.

Other Solar Energy Programs (Chapter 5)

The diversity of non-Federal solar energy programs includes activities at the international, state, university, industrial, and individual levels.

The United States is involved with a number of other countries in developing and deploying solar technologies. Cooperative efforts are grouped into three categories. International agencies such as the International Energy Agency and the Committee on the Challenges of Modern Society participate in information exchange and cooperative efforts in alternative energy sources. Specific bilateral agreements and programs exist between the United States and France, the U.S.S.R, Spain, Japan, Denmark, and Saudi Arabia. Federal and other agencies (NSF, DOE, the United States-Israel Bi-National Science Foundation, and the International Atomic Energy Commission) also collaborate with foreign universities.

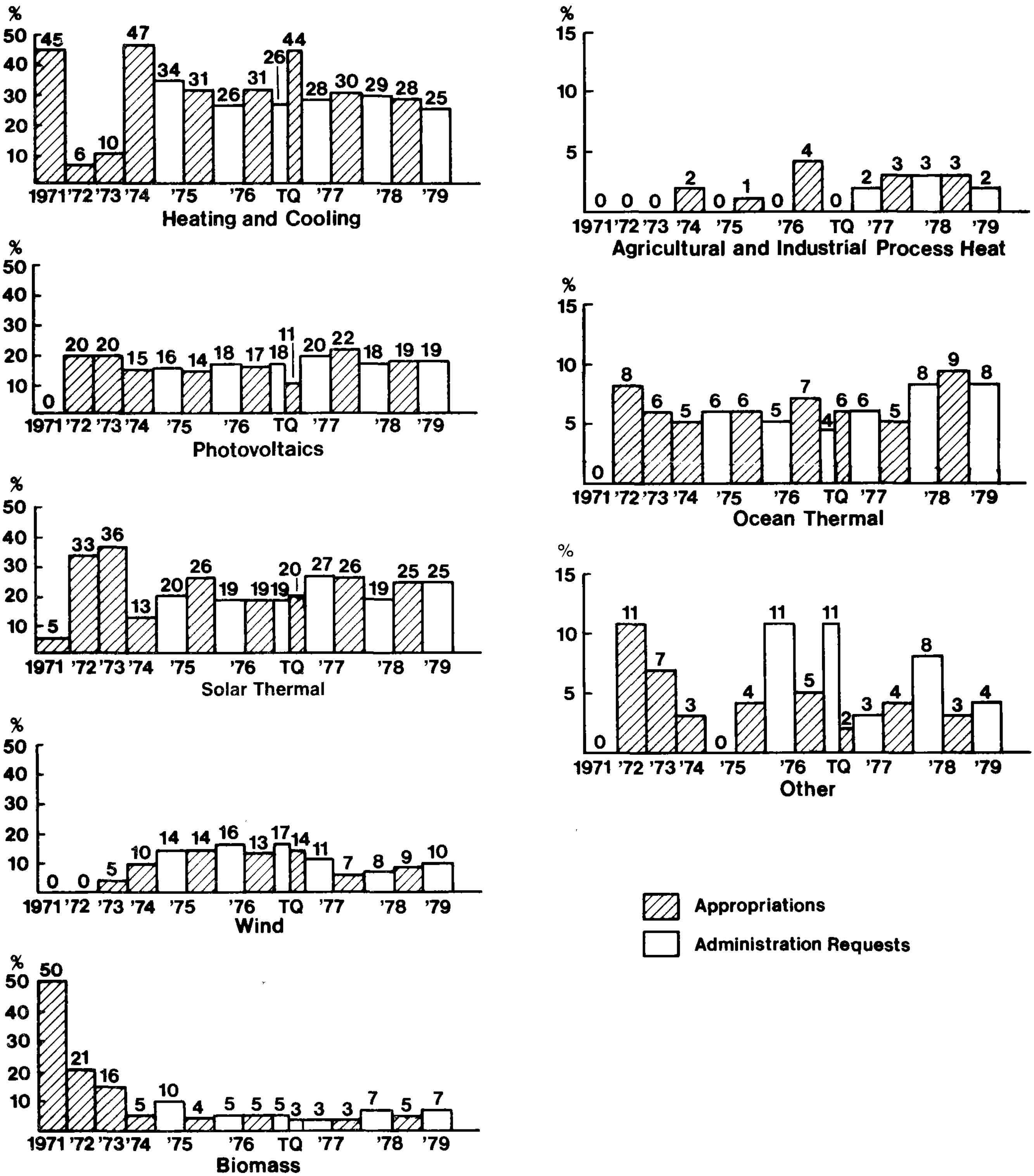
Individual states have developed flexible policy strategies reflecting regional differences. Activities include collecting and disseminating information; changing building codes; and, most important, enacting solar legislation (incentives, standards, energy consumption analysis, energy disclosure and solar rights). Local governments have major responsibilities for comprehensive land-use planning. Many localities have enacted laws favorable to rapid commercialization of solar technologies.

Universities and colleges provide four essential ingredients to support the Federal program: a broad range of professional talents; training; online research staffs and facilities; and supportive functions to the community. Funding for basic research at these institutions has provided the impetus for many innovations.

Over 700 firms are involved in manufacturing, distributing, and installing solar equipment. Companies involved in solar heating and cooling of buildings, the most widely commercialized solar technology, have increased sales dramatically. Wind energy conversion systems, to pump water and generate electricity, and photovoltaics also are growing rapidly. This young industry is characterized by rapid turnover of relatively small firms although several large corporations also are expanding efforts in solar technologies.

Individuals and groups without government funding are increasingly building and using solar technologies on their own. Recently, the National Center for Appropriate Technology, and Appropriate Technology International, have received institutional funds totaling $10 million to support small scale projects.

Figure 1-2. DISTRIBUTION OF ADMINISTRATION REQUESTS AND APPROPRIATIONS AMONG EIGHT SOLAR TECHNOLOGIES, 1971-1979



Note: Figures for Administration Requests not available for FY1971-1974, or for Appropriations for FY1979.

Major Forces Affecting the Future of Solar Energy (Chapter 6)

Recent studies identify the trends and events which are likely to have a major influence on the role of solar energy in America's future. They include economic, social, environmental, international, R&D, and policy factors.

A major economic factor will be the price and availability of oil and natural gas; this may be the most important determinant of future solar energy commercialization. The higher the prices and the more restricted the availability of these now-dominant fossil fuels, the greater becomes the potential market for solar technology. The economic valuation of solar energy also will be influenced by the future relation between energy consumption and Gross National Product; solar technology will play an important role in increasing the energy efficiency of the economic process. Another important economic factor in solar energy's future is labor and employment. In general, solar energy systems are more labor-intensive than are alternative energy sources. Future trends in employment and unemployment, labor relations, unionization, etc. should have an important influence on solar development. Other significant economic factors affecting the future evolution of solar energy in the United States are:

- capital requirements and life-cycle costs of competing energy systems;
- the structure and control of the United States energy industry;
- physical resource requirements of alternative energy systems.

Among social factors, trends in population growth and distribution will influence the marketing, distribution, and application of solar technology. Changing lifestyles—including patterns of work, education, leisure, marriage, family, and community relations—will dictate how, when, where, why, and by whom solar energy is used in the future. Recently, a body of opinion has developed in the United States which views the present level of centralization of political and economic control as excessive and which actively seeks decentralization; the impact of the decentralization movement on solar development will be profound. In general, the values, goals, preferences, ideals, and ethics of the American people will be a powerful determinant of solar energy development. Whether increasingly technocratic institutions will be responsive to changing human values and goals remains to be seen.

Environmental factors are likely to be extremely influential in solar energy's future. The reliability of solar power will depend on the stability of climate conditions over periods of decades at least. However, some researchers now believe that the world's climate recently has been unusually favorable and may soon return to a less favorable norm. One group of researchers believes that further expansion in the use of fossil fuels as an energy source will add so much carbon dioxide to the atmosphere that catastrophic climate effects will result. If further research indicates that a major hazard exists, one result could be accelerated development of solar energy. Solar plants will require large amounts of land compared to the land use of most conventional power generation. On the other hand, the total land area required even for large scale solar energy use is modest; the total present energy consumption of the United States could be supplied by the sunlight falling on only 2% of the nation's land area.

The most important international issue affecting solar energy's future obviously is the politics of oil. Studies by the CIA and at MIT indicate a worldwide shortage of oil beginning in the 1980s. America's use of solar energy will be tied to the nation's response to the world oil problem. Other international factors will be influential. The interest of less developed countries in solar development may determine the significant early markets for solar energy. In the absence of more effective efforts in population control, one result will be an ever-worsening crunch between population and food supply in many parts of the world; this could have a major impact on solar development.

Future trends in research and development obviously will be very important. The expected learning curve for new solar technologies may be highly influential on both public and private planning for solar development. The Federal R&D program in solar energy will influence the rate of innovation in solar technology. Technological breakthroughs cannot be predicted but may occur to make solar sources of electricity, and of liquid and gaseous fuels, available much sooner than presently expected.

Finally, the complex set of Federal energy and economic policies, and a variety of state and local government policies, will do much to determine how fast and how far solar energy penetrates into America's energy future.

PART II — SOLAR TECHNOLOGY PROFILES

"Solar Energy" includes a dozen or more technology categories, each of which is comprised of several specific technical systems. The following summarizes the important solar technology developments of the past year:

- Over 10 million square feet of solar heating and hot water collector were sold during 1977. Design techniques continued to improve; industry-approved standards do not appear to be far off. (Chapter 7)
- Solar cooling systems are not yet cost-effective, but rapid development of a range of novel approaches is underway. (Chapter 8)
- Passive solar designs are presently cost-effective, and Federal interest in passive design is growing. Numerous nontechnical, noneconomic problems are now being addressed. (Chapter 9)
- Demonstrations predominated in the Agricultural and Industrial Process Heat (AIPH) portion of the Federal solar program. Wide differences exist in estimates of the potential of this market. (Chapter 10)
- Solar cell prices continued to decline during 1977 at a rate

consistent with Federal goals. Research, development, and demonstration projects continued in all forms of photovoltaics: flat-plate, concentrators, single crystal, thin-films, etc.; the largest photovoltaic demonstration initiated in 1977 was a 25 kW_p irrigation pumping system in Mead, Nebraska. (Chapter 11)

- Test facilities became operational during 1977 at the Sandia-Albuquerque facilities for both central tower (5 MW_e) and dispersed (total energy) solar thermal facilities. A 400 kW_t central receiver in Atlanta, Georgia, and a 25 hp irrigation facility in Willard, New Mexico, became operational. The Jet Propulsion Laboratory also became the prime contractor during 1977 of a major new program in community-sized power systems. (Chapter 12)

- A 200 kW wind generator was installed in November 1977, at Clayton, New Mexico, to become the largest operational wind machine in the world. The 100 kW machine at Plum Brook, Ohio, continued to provide both useful power and experimental data. A 17 m diameter, vertical-axis generator was installed at the Sandia-Albuquerque Laboratories in March 1977, and has performed satisfactorily since then. Numerous small wind machines are now undergoing extensive tests at a DOE center established this year at Rocky Flats, Colorado. Several technical modifications already have resulted from these tests. (Chapter 13)

- Ocean Thermal Energy Conversion (OTEC) systems are approaching the field test stage. Major concerns about biofouling and heat transfer coefficients have been reduced, if not eliminated, by initial tests performed during 1977. Design studies continued on both full scale and first generation, ocean-based test facilities. (Chapter 14)

- The solar power satellite (SPS) system received increased attention during 1977. Reports provide details of several alternative approaches. The complex issues raised by further SPS development are being studied seriously. (Chapter 15)

- Fuels from Biomass (FFB) is receiving increased attention because of its near-term potential, particularly for direct combustion applications. Construction was begun during 1977 on an anaerobic digestion plant, and testing was initiated on a prototype tree harvester. Studies were completed or in process for other major hardware tests. (Chapter 16)

- Among the advanced solar technologies are photoconversion (Chapter 17) and thermochemical conversion (Chapter 18) of sunlight to electricity and to fuels. Promising research results have been reported.

Some other advanced technologies have studies underway that may lead to major Federal program commitment. Among these are efforts to develop energy from tides, waves, and salinity gradients.

In addition to the economic conversion of the various forms of solar energy, the storage of energy will continue to play a major role in the future introduction of solar energy systems. Thermal and chemical (Chapter 19) and electrochemical and mechanical (Chapter 20) approaches to energy storage are undergoing rapid development. Technical feasibility of new storage mechanisms was demonstrated in 1977, and numerous analytical studies were completed.

Finally, activities in materials research related to solar energy (Chapter 21) and in solar energy resource assessment (Chapter 22) included advances of both a theoretical and practical character, such as new measurement techniques, new materials, new models, and new understanding of basic physical phenomena.

2. HISTORY OF THE FEDERAL SOLAR PROGRAM

CHRONOLOGY

The Early Years: the 1950s and 1960s

Probably the earliest reference in public policy documents to the need for support for solar energy research was contained in the Materials Policy Commission report[1] to President Truman in 1952. The so-called "Paley Report" stated:

> . . . Efforts made to date to harness solar energy economically are infinitesimal. It is time for aggressive research in the whole field of solar energy—an effort in which the United States could make an immense contribution to the welfare of the Free World.[2]

Throughout most of the 1950s, however, Federal research in solar energy was only indirect. For example, the National Science Foundation (NSF) supported "research projects in disciplinary areas of importance to solar energy research, e.g., solid state physics of photovoltaic devices."[3]

In 1958 the National Aeronautics and Space Administration (NASA) was founded and began doing solar-related research. NASA recognized the potential in solar technology to solve two of the space program's major challenges—thermal control and electrical power for spacecraft. By 1961, NSF was annually supporting one or two projects which had "relatively direct interest to solar energy application."[4] Both NASA and NSF continued to carry out or sponsor solar-related research during the 1960s. Through 1970, however, the direct Federal solar budget totaled only about $100,000 annually.

In 1964, the report *Energy R&D and National Progress*[5] was issued. Also known as the Cambel Report (for the study director, Ali B. Cambel), this document reiterated the massive potential of solar energy:

> Enormous and continuous quantities of solar energy are available, far exceeding the foreseeable demand. If only 2% of the land were used for solar energy recovery and if the average efficiency of converting solar energy to heat and power were 10%, energy from solar radiation could, by itself, permit nearly a five-fold expansion in the nation's energy use.[6]

However, the Report foresaw only limited utilization of solar energy in the absence of major technical breakthroughs.

In the 1950 to 1970 period, solar-related bills were introduced in Congress by Representatives Murdock, Miller, Hosmer, and Anfuso, and by Senators Bible, Humphrey, and Tower. (Some of these bills were identical, introduced simultaneously by a Representative and a Senator.) None was passed into law.

Curiously, these two decades of Federal inaction coincided with an upsurge of popular and scientific interest in solar energy. A 1952 government survey, looking at the enthusiasm expressed in contemporary magazines, predicted 13,000,000 solar-heated and cooled houses by 1975. In 1960, there were about 25,000 solar hot-water units in use in Florida and California (and 250,000 in Japan). The first half of the 1950s witnessed several large solar conferences; the decade as a whole saw a seven-fold increase in solar publications, from 126 to 878. The number of publications again swelled in the 1960s, totaling some 2144 (including single articles).[7]

1971-1973: Awakening Interest

In the early 1970s there was a growing interest in solar energy at the Federal level. In FY71, the budget for solar research, at the time allocated to NSF, passed the $1 million mark. In his energy message of June 4, 1971, President Nixon stated: "The sun offers an almost unlimited supply of energy if we can learn to use it economically."[8]

In December 1972, three reports relating to solar energy were published. NSF and NASA published a joint report, "Solar Energy as a National Energy Resource,"[9] recommending a 15-year, $3.5 billion Federal-private solar energy research effort. Such a radical departure from previous policy, the report concluded, could enable solar energy to provide economically by 2020 up to 35% of the nation's heating and cooling, 30% of the gaseous fuels, 10% of the liquid fuels, and 20% of the electric energy requirements. The NSF/NASA report is particularly significant in being the first major Federal effort to actually quantify solar energy's potential.

A second report, "Solar energy Research,"[10] was prepared at the end of 1972 for the House Committee on Science and Astronautics (now the Committee on Science and Technology). This report included separate statements by NSF, NASA, the National Bureau of Standards (NBS), and the Congressional Research Service (CRS). NSF and NASA based their statements on their previously mentioned joint study, and the statements are therefore quite similar. In this report containing separate statements, both NSF and NASA indicated a desire to be the lead Federal agency for solar research. The NBS statement focused on technical aspects of heating and cooling.

In this otherwise somewhat optimistic document, CRS struck a cautionary note. It concluded that:

> Solar energy is at best a very long range future solution to the problem of meeting U.S. requirements for electrical energy. . . . There is always, of course, the possibility that research will turn up the unexpected but useful discovery. More to the point, solar energy can be a useful alternative ultimate source of power in the event that the technologies of the breeder reactor and fusion power fail to mature or fail to win public acceptance.[11]

The third December 1972 document was the Report of the Task Force on Energy of the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics.[12] Headed by Rep. Mike McCormack, this Task Force echoed the NSF/NASA recommendation for much greater funding of solar research:

> Because of its continuous and virtually inexhaustible nature, Solar Energy R&D should receive greatly increased funding. Near-term application of solar power for household uses seems likely, and central station terrestrial solar power and satellite solar power are attractive long-term possibilities.[13]

In June 1973 President Nixon announced a $10 billion, five-year Federal energy research and development program. The chairman of the AEC, Dixy Lee Ray, was assigned to develop a plan to implement the program. Sixteen subpanels were created to carry out background studies for the plan. Subpanel IX prepared a report on solar energy. The subpanel's report,[14] issued on October 27, 1973, was highly optimistic about solar energy's potential, estimating that the sun could provide 10% to 30% of the nation's energy requirements in 2000 and as much as 50% by 2020. The subpanel recommended a five-year program with either a "minimum" budget of $409.9 million or an "accelerated/orderly" plan costing $1.056 billion.

However, the final AEC report ("The Nation's Energy Future,"[15] also known as the Dixy Lee Ray Report), did not include Subpanel IX's ideas. Instead, it recommended $200 million for solar energy over five years—less than half the "minimum" suggested.

From 1971 to 1973, several solar-related bills were introduced in Congress by Senators Moss and Gravel, and by Representatives Runnels, Vanik, and McCormack. The last is particularly noteworthy. Introduced on October 16, three days before the Arab oil embargo began, Rep. McCormack's "Solar Heating and Cooling Demonstration Act of 1973" (H.R. 11864) gained the distinction of being the first explicit solar energy bill to be enacted into law (early in 1974).

As in the 1950-1970 period, Federal involvement with solar energy between 1971 and the 1973 oil embargo was seemingly at odds with the situation in the private sector. The Federal budget for solar energy more than tripled from FY71 to FY73 ($1.2 million to more than $4 million); four Federal reports, as described above, gave relatively optimistic predictions about solar energy's future if funding were greatly increased; and in 1973, NSF, NASA, and the House Committee on Science and Astronautics all actively supported a higher level of funding for solar R&D. On the other hand, the early 1970s were dismal for solar energy in the private sector. The headquarters of the International Solar Energy Society (ISES) moved to Australia because there was insufficient support to maintain it at Tempe, Arizona. The ISES journal, *Solar Energy*, ceased publication for periods of time in the early 1970s for the same reason.[16]

1973 - 1977

While the early 1970s saw a significant increase in Federal interest in solar energy, it was the Arab oil embargo and subsequent quadrupling of oil prices growing out of the October 1973 Middle East War that forced the nation to begin to take solar energy seriously. The sudden demonstration of U.S. vulnerability to energy supply curtailments and extreme price increases caused deep concern. The immediate governmental responses were both executive and legislative. President Nixon issued a call for "energy independence," and he directed the FEA to draw up a series of blueprints for Project Independence. The Solar Task Force, established in April of 1974 and chaired by NSF, completed its work and published the Project Independence Blueprint in Solar Energy[17] in November of that year. The Blueprint developed two possible Federal programs, "accelerated" and "business-as-usual." In the former, which postulated a Federal role in commercialization as well as in R&D, solar energy could provide as much as 21.6% of national energy supplies by 2000. In the business-as-usual case, involving only Federal R&D, the 2000 figure was 6.0%. However, the Blueprint cautioned that the actual figures would likely be more modest because it is unrealistic to expect all solar technologies to reach their maximum use.

A second post-embargo report was issued in December 1974 by NSF. Entitled "National Solar Energy Program,"[18] it set forth a five-year budget for solar which was consistent with the Project Independence Blueprint. The budget proposed $50 million for FY75, growing to $325.8 million by 1979; the total five-year figure was $1072 billion.

The NSF-proposed budget was not substantially different from those of such earlier documents as the 1972 NASA/NSF report and the Subpanel IX report. In the light of the sense of crisis prevailing in 1974, this may seem disappointing. However, the Ford Administration made the first substantive Federal commitment to solar energy development, requesting the $50 million in funding for solar energy which NSF had recommended.

Legislators also responded to the oil crisis. Members of Congress introduced a thousand energy bills, and state legislators, several times that number.[19] In 1974, Congress finally passed several solar energy laws. These included the Solar Heating and Cooling Demonstration Act (PL 93-409) and the Solar Energy Research, Development, and Demonstration Act (PL 93-473), which established the Solar Energy Research Institute (SERI) and the Solar Energy Information Data Bank (SEIDB). Congress also addressed the critical need to pull together the nation's energy research and development programs (including solar) into a single agency; in 1974 it created the Energy Research and Development Administration (ERDA). (Up until that time, NSF was the lead agency for solar R&D, while the Atomic Energy Commission and several national labs had initiated solar programs. Also, NASA had expanded its program to include terrestrial applications for solar energy.) Congress early in the year had created the Federal Energy Administration (FEA) out of the Federal Energy Office (FEO); the FEA was exclusively responsible for policy and commercialization activities. Table 2-1 summarizes both this enabling legislation and the principal solar acts.

One of the first reports produced by ERDA (in response to the several solar-related laws passed in 1974) was "A National Plan for Solar Heating and Cooling" (ERDA-23).[20] It was soon followed in June 1975 (as required by PL 93-577) by "A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future" (ERDA-48).[21] The latter document, which addressed the Federal R&D program in all energy sources rather than just in solar, recommended the following national policy and energy technology goals:

National Policy Goals

- maintain the security and policy independence of the nation;
- maintain a strong and healthy economy, providing adequate opportunities and allowing fulfillment of economic aspirations (especially in the less affluent parts of the population);
- provide for future needs so that future life styles remain a matter of choice and are not limited by the unavailability of energy;
- contribute to world stability through cooperative international efforts in the energy sphere;
- protect and improve the Nation's environmental quality by assuring that the preservation of land, water, and air resources is given high priority.

Table 2-1. PRINCIPAL SOLAR LEGISLATION

- *Federal Energy Administration Act of 1974.*[a] (PL 93-275) created FEA with the authority to plan and conduct programs related to the production, conservation, use, control, distribution, rationing, and allocation of all forms of energy.
- *Solar Heating and Cooling Demonstration Act of 1974.*[b] (PL 93-409) provided for the development and demonstration of solar heating and cooling technology in residential and commercial buildings. Also provides for the dissemination of information which results from these activities.
- *Energy Reorganization Act of 1974.*[c] (PL 93-438) brought together in ERDA all Federal activities related to energy R&D. Relative to solar energy, the Act provided for the transfer to ERDA of all NSF functions related to solar heating and cooling of buildings. Actual transfer of solar authority from NSF to ERDA went beyond the solar heating and cooling application and included all major projects within NSF's RANN program.
- *Solar Energy Research, Development, and Demonstration Act of 1974.*[d] (PL 93-473) set forth a comprehensive Federal solar energy program in three areas: (a) resource determination and assessment; (b) research and development; and (c) demonstration. The Act also established a Solar Energy Research Institute and Solar Energy Information Data Bank.
- *Non-Nuclear Energy Research and Development Act of 1974.*[e] (PL 93-577) established a national program of basic and applied R&D addressing all potentially beneficial energy sources and utilization technologies.
- *Department of Energy Organization Act of 1977.*[f] (PL 95-97) consolidated the energy functions of ERDA, FEA, and several other Federal agencies into the Department of Energy.

a. 15 U.S.C. 761 et. seq.

b. 42 U.S.C. 5501 et. seq.

c. 43 U.S.C. 5801 et. seq.

d. 42 U.S.C. 5551 et. seq.

e. 42 U.S.C. 5901 et. seq.

f. 42 U.S.C. 7101 et. seq.

Energy Technology Goals

- expand the domestic supply of economically recoverable, energy producing raw materials;
- increase the use of essentially inexhaustible domestic energy resources;
- efficiently transform fuel resources into more desirable forms;
- increase the efficiency and reliability of the processes used in energy conversion and delivery systems;
- transform consumption patterns to improve energy use;
- increase end use efficiency;
- protect and enhance the general health, safety, welfare, and environment related to energy;
- perform basic and supporting energy research and technical services related to energy.

President Ford changed the national policy goals somewhat in his 1976 Energy Message, and these revised goals were reiterated in ERDA-76-1,[22] an April 1976 update of ERDA-48. The revised goals included:

- provide energy to the American consumer at the lowest possible cost consistent with the need for secure energy supplies;
- make energy decisions consistent with our overall economic goals;
- balance environmental goals with energy requirements;
- rely upon the private sector and market forces as the most efficient means of achieving the Nation's goals, but act through the government where the private sector is unable to achieve our goals;
- seek equity among all our citizens in sharing of benefits and costs of our energy program;
- coordinate our energy policies with those of other consuming nations to promote interdependence, as well as independence.

These remained the stated goals of the U.S. energy program until President Carter put forth a new set in his National Energy Plan[23] (NEP) in April 1977.

In addition to ERDA-48, in June 1975 ERDA published ERDA-49, "Definition Report: National Solar Energy Research, Development, and Demonstration Program"[24] (as required by PL 93-473). This report, addressed specifically to solar energy, was relatively cautious in its expectations, estimating that solar energy could supply only 7% of national energy demands by 2000 and 25% by 2020, assuming significant cost reductions. The 1976 update of ERDA-48, ERDA-76-1, included a section on solar energy. It cited solar heating and cooling as a high priority near- and mid-term technology, and solar electric as high priority in the long term.

ERDA was supposed to update annually its overall energy R&D reports (ERDA-48, 76-1) and its solar report (ERDA-49). The annual update in 1977 was prepared in draft form as ERDA-77-1, which addressed the total ERDA program. However, the April publication of the NEP, setting new energy goals (as noted above), made the ERDA-77-1 draft obsolete. Instead, the agency issued a much abbreviated ERDA-77-1[25] which was general in nature.

Besides President Carter's NEP, the most significant Federal energy event in 1977 was the creation of the Department of Energy (PL 95-97), which began operations on October 1. The consolidation of energy activities and their elevation to Cabinet-level status gave evidence of the increasing importance attached by the Federal Government to the nation's energy problems.

Two solar energy reports issued in 1977 deserve mention. In June, the Office of Technology Assessment published the draft of its massive 2-volume study, *Applications of Solar Technology to Today's Energy Needs*.[26] This report does not explicitly address the national program. However, in "assessing the technical, economic, legal, regulatory, and institutional implications of large-scale use of on-site solar energy,"[27] it indirectly offered an alternative to the Federal program.

In December, the Council on Environmental Quality published its draft of *Solar Energy: A Review of Progress and Recent Policy Recommendations*.[28] In addition to summarizing briefly the state-of-the-art of the various solar technologies, the report discussed five proposals which "have been offered [in recent months] for improving the federal effort to promote solar energy":

- further expand financial incentives and eliminate institutional barriers;
- adopt needed changes in the Federal R&D program relating to solar and other alternative energy sources (such changes include, among others, increased emphasis on small scale and onsite technologies, and increasing the solar staff at DOE);
- institute price reform for competing fuels;
- develop the solar market available in less developed countries;
- improve Government programs for the purchase of solar equipment for Federal use.[29]

In 1976, ERDA Assistant Administrator Robert Hirsch requested from ERDA's General Advisory Committee (GAC) a review of the solar program's balance. The GAC (formerly the GAC of the Atomic Energy Commission) contracted with SRI International to do the report. It also decided to form itself, with the additon of six national solar experts, into the Solar Working Group (SWG) to write its own report. The SRI report, "A Comparative Evaluation of Solar Alternatives: Implications for Federal R&D,"[30] was published in January 1978. Through a complex and far-reaching benefit/cost analysis, SRI ranked the various solar technologies in the near-term (1985), intermediate-term (2000), and long-term (2020). The team found that SHACOB, biomass, and wind were the most promising in both the near- and intermediate-terms, and wind, SHACOB, and photovoltaics in the long-term.

The SWG relied on the SRI data and methodology but analyzed it differently. Its report, "Solar Energy Research and Development: Program Balance,"[31] called for greater emphasis on biomass, thin-film photovoltaics, and basic research; less emphasis on OTEC, single-crystal silicon and concentrator photovoltaics, and solar thermal demonstrations other than Barstow; and no basic changes in wind and SHACOB (except cooling, whose demonstration should be deferred).

The magnitude of the Federal Government's increased interest in solar energy following the Arab oil embargo and OPEC price rise is most striking in its budget. From the FY74 funding level of $15 million, the solar budget rose to approximately $400 million in FY78.

Notes

[1]U.S. President's Commission on Materials Policy, *Resources for Freedom*, by William S. Paley (chairman), (Washington, D.C.: Government Printing Office, June 1952).

[2]U.S. Congress Congressional Research Service, Science Policy Research Division, *Solar Energy Legislation Through the 94th Congress* (Washington, D.C.: Government Printing Office, 1977), p. 4.

[3]U.S. Congress, House of Representatives, Committee on Science and Technology, *Solar Energy Research*, 92nd Congress, 2nd session (Washington, D.C.: Government Printing Office, December 1972), p. 46.

[4]U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, *Solar Heating and Cooling*, Hearing, 93rd Congress, 2nd session, on S. 2658 and H.R. 11864, Solar Heating and Cooling Demonstration Act, February 25, 1974 (Washington, D.C.: Government Printing Office, 1974), p. 105.

[5]U.S. Executive Office of the President, Office of Science and Technology, *Energy R&D and National Progress*, prepared for the Interdepartmental Energy Study by the Energy Study Group under the direction of Ali Bulent Cambel (Washington, D.C.: Government Printing Office, 1964).

[6]Ibid., p. 339.

[7]Aden B. Meinel and Marjorie P. Meinel, *Applied Solar Energy*, (Reading, Mass.: Addison-Wesley Publishing Company, 1976), pp. 25-27.

[8]U.S. President, "Special Message to the Congress on Energy Resources" (June 4, 1971), *Public Papers of the Presidents of the United States: Richard Nixon* (1971), by the National Archives and Records Service (Washington, D.C.: Government Printing Office, 1972), p. 708.

[9]*Solar Energy as a National Energy Resource*, prepared by the NSF/NASA Solar Energy Panel, NSF-RANN 73-001, December 1972.

[10]Committee on Science and Technology, *Solar Energy Research*, (1972).

[11]Ibid., p. 119.

[12]U.S. Congress, House Committee on Science and Aeronautics, Subcommittee on Science, Research, and Development, *Energy Research and Development*, report of the Task Force on Energy, 92nd Congress, 2nd session (Washington, D.C.: Government Printing Office, December 1972).

[13]Ibid., p. 224.

[14]Subpanel IX, *Solar and Other Energy Sources*, prepared for the Chairman, U.S. Atomic Energy Commission in support of the development of a comprehensive Federal energy research and development program to be recommended to the President on December 1, 1973 (WASH 1281-9), October 27, 1973.

[15]*The Nation's Energy Future*, A Report to Richard M. Nixon, President of the United States, submitted by Dr. Dixy Lee Ray, Chairman, United States Atomic Energy Commission, WASH 1281, December 1, 1973.

[16]Meinel and Meinel, *Applied Solar Energy* (1976), p. 28.

[17]Federal Energy Administration, Project Independence Blueprint, *Solar Energy*, final task force report under the direction of the National Science Foundation (Washington, D.C.: Government Printing Office, November 1974).

[18]National Science Foundation, *National Solar Energy Program* (Washington, D.C.: Government Printing Office, December 1974).

[19]Jerry Gray, "Energy Since the Oil War," *Astronautics and Aeronautics*, 13 (November 1975), p. 16.

[20]Energy Research and Development Administration, Division of Solar Energy, *National Program for Solar Heating and Cooling (Residential and Commercial Applications)*, ERDA-23, October 1975. Later amended version ERDA-23a.

[21]Energy Research and Development Administration, Division of Solar Energy, *A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future*, ERDA-48 (Washington, D.C.: Government Printing Office, June 1975).

[22]Energy Research and Development Administration, Division of Solar Energy, *A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future*, ERDA-76-1 (Washington, D.C.: Government Printing Office, April 1976).

[23]U.S. President, *The National Energy Plan* (Washington, D.C.: Government Printing Office, April 1977).

[24]U.S. Energy Research and Development Administration, Division of Solar Energy, *Definition Report: National Solar Energy Research, Development, and Demonstration Program*, ERDA-49 (Washington, D.C.: Government Printing Office, June 1975).

[25]U.S. Energy Research and Development Administration, *A National Plan for Energy Research, Development, and Demonstration*, ERDA-77-1 (Washington, D.C.: Government Printing Office, June 1977).

[26]U.S. Congress, Office of Technology Assessment, *Application of Solar Technology to Today's Energy Needs*, Prepublication draft, June 1977.

[27]Ibid., p. ii.

[28]U.S. President, Council on Environmental Quality, *Solar Energy: A Review of Progress and Recent Policy Recommendations* (Washington, D.C.: Government Printing Office, December 1977).

[29]Ibid., pp. 16-23.

[30]U.S. Department of Energy, Solar Working Group, *A Comparative Evaluation of Solar Alternatives: Implications for Federal RD&D*, Jeffrey G. Witwer, Project Leader, Final Report by SRI International, SRI Project 6375, Number EA-77-C-01-2663, January 1978.

[31]U.S. Department of Energy, Solar Working Group, *Solar Energy Research and Development*, Charles J. Hitch, chairman, advance copy, February 1978.

3. NATIONAL ENERGY PLAN—SOLAR ENERGY IMPLICATIONS

INTRODUCTION

In April 1977, President Carter published his National Energy Plan. The legislative elements of the Plan (as proposed in the National Energy Act) will not be fully reflected in energy legislation ultimately enacted by Congress. Nevertheless, the Plan represents the most important public policy statement on energy of the past year, because it reflects the thoughts and intentions of the Administration that will be in office for the next three years.

This chapter looks at the NEP from several viewpoints. First, it reviews the outline: the principles, goals, objectives, and strategies that guide the Plan, as well as the Plan's specific proposals. It then notes the most important differences between this framework and that of the previous Administration. Third, the bulk of the chapter is devoted to a discussion of the solar issues arising from each of the Plan's guiding principles and goals. Last is an account of the Congressional action on the NEP, focusing on the solar provisions.

OUTLINE OF THE NEP

The National Energy Plan includes ten principles, three objectives, three strategies, and seven goals. The principles state the basic premises upon which the Plan rests. Each objective puts forth a general desired result for the short term, medium term, or long term; the strategies identify how the objectives are to be met. The goals are measurable, specific actions to be achieved by 1985.

Principles

Although all ten principles are general in nature, the NEP divides them into two groups. The first five "establish the context in which energy policy must be formulated"; that is, they are more generic to overall federal policymaking than are the second five.

1. The energy problem can be effectively addressed only by a Government that accepts responsibility for dealing with it comprehensively, and by a public that understands its seriousness and is ready to make necessary sacrifices.

2. Healthy economic growth must continue.

3. National policies for the protection of the environment must be maintained.

4. The United States must reduce its vulnerablility to potentially devastating supply interruptions.

5. The United States must solve its energy problems in a manner that is equitable to all regions, sectors, and income groups.[1]

The second five principles are "fundamental to the proposed comprehensive National Energy Plan." Although still basic premises, principles 6-10 are more specifically related to energy and to the goals of the NEP.

6. The cornerstone of the NEP is that the growth of energy demand must be restrained through conservation and improved energy efficiency.

7. Energy prices should generally reflect the true replacement cost of energy.

8. Both energy producers and consumers are entitled to reasonable certainty as to Government policy.

9. Resources in plentiful supply must be used more widely, and the nation must begin the process of moderating its use of those in short supply.

10. The use of nonconventional sources of energy must be vigorously expanded.[2]

Objectives and Strategies

The objectives add a time element to the NEP by setting one priority each for the near, medium, and long terms. The objectives are more specific than the principles, but the fact that they encompass the entire energy field in one statement for each of the time periods insures their relative broadness. The objectives are:

a. In the short run, to reduce dependence on foreign oil and to limit supply interruptions.

b. In the medium term, to weather the eventual decline in the availablility of world oil supplies caused by capacity limitations.

c. In the long term, to develop renewable and essentially inexhaustible sources of energy for sustained economic growth.[3]

The strategies identify, again in rather general terms, the means by which to reach the objectives. The strategies are:

a. Implementation of an effective conservation program for all sectors of energy use so as to reduce the rate of demand growth to less than 2 percent, thereby helping to achieve both the short- and medium-term goals.

b. The conversion of industry and utilities using oil and natural gas to coal and other more abundant fuels to reduce imports and make natural gas more widely available for household use, thereby helping to achieve both the short- and medium-term goals.

c. A vigorous research and development program to provide renewable and essentially inexhaustible resources to meet United States energy needs in the next century, thereby helping to achieve the long-term goal.[4]

Goals

The NEP calls on Congress to enact a Joint Resolution to commit the nation to a set of seven goals. These measurable 1985 targets bring together the various sections of the Plan into a single whole. They correlate with the principles, as will be shown in the next section; they seek to enable the nation to meet at least the short-run objective of reducing dependence on foreign oil. Also, the legislative proposals which make up the bulk of the Plan are geared to the goals. (However, the Administration makes it clear that the legislative proposals are not sufficient to meet the goals. The American people are also expected to act voluntarily.) The goals are:

- reducing annual growth of United States energy demand to less than 2 percent;
- reducing oil imports from a potential level of 16 million barrels a day to less than 6 million barrels, about one-eighth of total energy consumption;
- achieving a 10 percent reduction in gasoline consumption;
- insulating 90 percent of all residences and other buildings;
- establishing a strategic petroleum reserve of 1 billion barrels;
- increasing coal production on an annual basis by at least 400 million tons;
- using solar energy in more than 2½ million homes.[5]

Proposals

The NEP outlines a host of specific measures to implement these ideas. The primary ones include a series of taxes, tax credits, and prohibitions to induce utilities and industries to convert from oil and gas to coal; taxes on oil at the wellhead, to be refunded to consumers; higher prices for natural gas, but extended price regulation to cover not only interstate but also intrastate gas; utility rate reform; and a series of conservation measures. There are several solar proposals outlined in the NEP, most of which are considered conservation measures.

THE NEP: CHANGES IN GOALS AND PRINCIPLES

National goals and principles for energy policy took on high priority after the oil embargo of 1973. That event precipitated President Nixon's Project Independence, which was followed by ERDA 48 in 1975, by President Ford's Energy Message and ERDA 76-1 in 1976 (a short revised version was released in 1977), and by President Carter's National Energy Plan (NEP) in April 1977. All these documents, to a greater degree or lesser degree, set forth the context within which energy policy was to be formulated. However, we are concerned primarily with 1977, and implicitly with the present and future. These concerns lead us to focus on the changes in national energy goals or principles which took place in 1977; or more specifically, on how the Carter NEP differs from the Ford documents, which include the Energy Message and ERDA 76-1.

Principles and goals indicate where each Administration's basic priorities lie. Comparisons of these demonstrate those areas in which the Carter Administration's priorities differ from those of the Ford Administration. The following list is not meant to be exhaustive or detailed; rather, it focuses on those major changes in priorities made by the Carter Administration which have most impact on solar development.

Explicit Role for Solar Energy

Most important, the NEP includes 2.5 million solar homes by 1985 as one of its seven goals. This is significant for two reasons. First, it represents an improvement in the time frame for solar commercialization, since ERDA 76-1 assumes solar heating and cooling to be a mid-range (1985-2000) technology. Second, it is the first time that solar energy has appeared on a list of "national goals."

Moderation of Energy Demand Through Conservation

In setting a goal of reducing the annual rate of growth of energy demand to less than 2% by 1985, the NEP makes explicit the need for a different national attitude towards energy use. The Ford documents do not directly discuss reducing the energy demand growth rate. Further, the NEP's reduction in growth is to be accomplished through conservation, which not only is the subject of two goals (10% reduction in gasoline consumption and 90% insulation of all buildings), but also is called the "cornerstone" of the Plan (principle #6).

While conservation "[is] singled out for increased attention and [is] now ranked with several supply technologies as being of the highest priority for national action" in ERDA 76-1,[6] it cannot claim the preeminence as a goal given it by the NEP.

Strong Federal Role

The first principle of the NEP states the need for Federal responsibility for national energy policy. This represents a significant shift of emphasis from the 1976 Energy Message, which would "rely upon the private sector and market forces . . . but act through the government where the private sector is unable to achieve our goals;" and from ERDA 76-1, which recognizes "the paramount role of the private sector. . . ."[7]

Replacement Cost Pricing

President Ford's 1976 Energy Message includes the principles of providing energy at the lowest possible cost, given the need for secure supplies. In contrast, the NEP has as a principle the introduction of replacement cost pricing, or basing prices on the cost of supplying the *next* unit of energy. Theoretically,[8] the NEP is modifying the goal of cheap (subsidized) energy in favor of more rational and efficient allocation.

Commitment to the Physical Environment

The NEP's third principle is an unequivocal statement in support of environmental protection. In the fact sheet on the NEP, the third principle states in part, "Our energy problems have the same cause as our environmental problems—wasteful use of resources."[9] In contrast, President Ford advocated the principle of "balancing environmental goals with energy requirements."[10]

The difference between protecting the environment, including believing that environmental and energy problems come from the same source, and balancing the two, implying that they are opposites, is significant.

Lack of Strong International Commitment

Finally, the NEP does not include in its goals or principles any reference to an international position. The Ford Administration, however, had as a principle the "[coordination of] our energy policy with those other consuming nations to promote interdependence, as well as independence"; also one of its three goals was "to mobilize our technology and resources to supply a significant share of the free world's energy needs beyond 1985."[11]

SOLAR ISSUES RELATED TO THE NEP PRINCIPLES

The NEP divides its ten principles into two groups. However, the purposes of this review are better served by dividing the principles into three categories: national ends, specific means, and policy framework. "National ends" refer to those four general principles which are criteria for any federal policy, whether in energy or any other field: prosperity, security, environmental protection, and social equity. "Means" refers to the energy policies identified in the NEP to reach the larger ends: conservation, use of abundant resources, and expanded use of nonconventional power sources, including solar. Finally, three principles set out the framework in which energy policy is to be made: Federal responsibility, certainty vis-à-vis Government policy, and the use of replacement cost pricing.

Except for the principle of expanded use of nonconventional sources, these guiding ideas do not address solar energy specifically. However, the future of solar development is strongly affected by each of the principles. This section addresses the solar issues raised by the principles and the resultant goals. Notes referring to critiques of and comments on the NEP are included.

National Ends

Four principles in the NEP point toward general national ends: economic prosperity (principle #2), protection of the physical environment (principle #3), strategic security (principle #4), and equity (principle #5). Being among the first five, these principles are meant to be contextual rather than specifically goal-oriented. However, the principle of strategic security correlates directly with the goal to "establish a Strategic Petroleum Reserve of one billion barrels."[12] Also, several of the seven goals correlate indirectly. For example, meeting the goals of "reducing the annual growth of total energy demand to below 2%" and "reducing gasoline consumption 10% below its current level"[13] would help the physical environment.

ECONOMIC GROWTH (PRINCIPLE #2)

"HEALTHY ECONOMIC GROWTH MUST CONTINUE."

Solar Issues

- What are the effects of different types of solar deployment on the problems associated with an adverse balance of trade? of different time frames for such deployment?
- What are the effects of different types of solar deployment on unemployment?
- What are the effects of various forms of solar deployment on inflation? of different time frames for such deployment?
- What are the effects on economic growth of capital diversion to solar deployment?

PHYSICAL ENVIRONMENT (PRINCIPLE #3)

"NATIONAL POLICIES FOR THE PROTECTION OF THE ENVIRONMENT MUST BE MAINTAINED."[14]

Solar Issues

- What are the environmental hazards associated with the two "abundant" energy sources, coal and nuclear, that solar deployment would avoid?[15]
- What are the social costs associated with environmental degradation due to conventional sources? How should these costs be internalized?
- What is the magnitude of the environmental impacts, especially on land use, associated with large scale solar deployment?
- What is an appropriate solar subsidy to reflect the environmental advantages of solar energy (if any)?

STRATEGIC SECURITY (PRINCIPLE #4)

"THE UNITED STATES MUST REDUCE ITS VULNERABILITY TO POTENTIALLY DEVASTATING SUPPLY INTERRUPTIONS."

While this principle is phrased to address specifically the possibility of another oil embargo, implicitly it has to do with the broader concern of strategic security. This concern, in turn, raises several issues for solar energy use.

Solar Issues

- How can solar energy, as a resource indigenous to the United States, reduce the security problems inherent in dependence upon foreign energy (specifically oil)?
- Are there any critical solar materials which must be imported?
- How can solar energy, as a plentiful domestic resource in many developing nations, reduce international tensions resulting from these nations' difficulties in buying oil (and nuclear power)?[16]
- How can the developing nations provide the front-end capital required for solar technologies? To what degree will their use of solar be facilitated by the availability of semiskilled or unskilled labor forces?

EQUITY (PRINCIPLE #5)

"THE UNITED STATES MUST SOLVE ITS ENERGY PROBLEMS IN A MANNER THAT IS EQUITABLE TO ALL REGIONS, SECTORS, AND INCOME GROUPS."

Solar Issues

- How will solar energy impact minority groups (Chicanos, Blacks, Native Americans, rural, poor, etc.)?[17]
- How will different kinds of Government support—e.g., tax credits, low-interest loans, cash grants—affect different income groups' use of solar energy?[18] What options are available to insure that solar deployment is not regressive?
- Would it be equitable (or desirable) to allow homeowners and others who have their own solar systems all the deductions of energy companies?
- Do homeowners and others who want to provide their own energy through solar power have equitable access to the capital market?[19]
- To what extent is national policy equitable in its treatment of small and large companies involved in solar deployment?
- What regional inequities accrue to other energy sources (e.g., coal-fired power plants in New Mexico provide electricity for southern California)? What regional inequities might solar energy create or exacerbate (e.g., the same New Mexico land might be used for a solar power tower to provide the same electricity to southern California)?
- What should be the U.S. program of assistance to other nations in solar deployment?

Energy Means

The NEP includes three principles which address means by which changes in energy use can help meet our national ends. These principles include conservation (principle #6), increased reliance on domestically abundant energy sources and restriction of the use of scarce sources, (principle #9), and expansion of nonconventional sources (principle #10). The last principle is the only one to deal directly with solar energy; it is therefore of most interest to this report, and will be addressed in detail.

CONSERVATION (PRINCIPLE #6)

"THE CORNERSTONE OF THE NEP IS THAT THE GROWTH OF ENERGY DEMAND MUST BE RESTRAINED THROUGH CONSERVATION AND IMPROVED ENERGY EFFICIENCY."

The 1985 NEP goal for conservation[20] is to "reduce the annual growth of total energy demand to below 2%." Two other NEP goals partially describe how this is to be done:

—reduce gasoline consumption 10% below its current level;

—bring 90% of existing American homes and all new buildings up to minimum energy efficiency standards.[21]

Solar Issues

- How will conservation measures affect solar deployment?
- To what extent can conservation measures "buy time" for the development of such new energy sources as solar?

- Will the finance and labor infrastructure developed to meet conservation needs (in home insulation) be transferable to the solar industry (especially space and water heating)?

- Will the "conservation ethic" help turn public consciousness toward solar use, particularly of passive systems?

NEED FOR INCREASED SUPPLIES

Certain industry representatives are supportive of conservation but warn that it does not solve the basic problems of the need for increased supplies.[22]

Solar Issues

- Can the sun provide a significant portion of the energy supplies perceived as necessary by industry?

FUEL SCARCITY AND SUPPLIES (PRINCIPLE #9)

"RESOURCES IN PLENTIFUL SUPPLY MUST BE USED MORE WIDELY, AND THE NATION MUST BEGIN THE PROCESS OF MODERATING ITS USE OF THOSE IN SHORT SUPPLY."

The NEP's goal for 1985 to meet the ninth principle is to "increase coal production by two-thirds, to more than 1 billion tons per year."[23] In discussing this principle, however, the Administration also includes light-water nuclear reactors; it projects that nuclear power will supply more power by 1985 with the Plan than without it.[24] Thus, the Plan includes both coal and nuclear energy as abundant sources.

In addition, the NEP sets a goal for moderating the use of scarce resources to "reduce oil imports from a potential level of 16 million barrels per day to 6 million, roughly ⅛ of total energy consumption."[25]

As with conservation, the NEP's principle of emphasizing coal[26] and nuclear energy[27] raises several issues for solar energy.

Solar Issues

- Will coal and nuclear use require capital that might otherwise go to solar?

- How will a national decision to accelerate coal and nuclear deployment affect potential solar labor markets?

- Will the centralized electrification implied by nuclear power and coal burning foreclose noncentralizd, nonelectrified solar options? If so, what are the relative national economies or diseconomies?

- Which "conventional" technologies (e.g., coal-fired total energy systems) should be compared to the solar technologies? Which nascent technologies (e.g., coal liquefaction or gasification)?

- Will rapid development of nuclear power increase public concern about such perceived problems as sabotage and terrorism? If so, how will such public concern affect solar?

ALTERNATE SOURCES (PRINCIPLE #10)

"THE USE OF NONCONVENTIONAL SOURCES OF ENERGY MUST BE VIGOROUSLY EXPANDED."

The goal based on this last principle is to "use solar energy in more than 2½ million homes" by 1985.[28] Such use would entail space and/or water heating.[29]

It is appropriate that this report review not only the broad goal of 2.5 million solar homes but also other aspects of the NEP that relate to solar energy. First is the means to implement the goal. The Plan proposes an initial tax credit of 40% of the first $1000 and 25% of the next $6400; the credit would decline by 1985 to 25% of the first $1000 and 15% of the next $6400. "The credit would be supported by a joint Federal-State program of standards development, certification, training, information gathering, and public education."[30] Second, business and industry could use solar equipment for the additional 10% investment tax credit proposed by the NEP for energy conservation measures.[31] Third, "The Administration will request appropriation of up to $100 million over the next three years to add solar hot water and space heating to suitable Federal buildings to reduce consumption of conventional fuels and demonstrate the feasibility of widespread solar energy use."[32] Fourth, under the utility reform section, the NEP includes "a prohibition of discrimination by electric utilities against solar and other renewable energy sources."[33]

In various parts of the NEP, the Administration also outlines its R&D solar priorities. These include photovoltaics and, in the long term, central station solar electric power systems;[34] solar heating and cooling demonstration; solar agricultural and industrial processes applications; development of better ways to use agricultural and forestry residues, water-based energy crops, and animal waste (biomass); and development and demonstrations of solar and wind for irrigation pumps and other rural applications (for FY78);[35] and research in solar cooling and allied technology and on small wind systems, and demonstration of substituting wood-derived biomass for fuel oil.[36] Finally, the Plan states that the R&D program which is added to the already existing program "emphasizes small, dispersed, and environmentally sound production and use of energy, particularly renewable energy. It also seeks to redress the advantage enjoyed by big business in the Government's current research and development program."[37]

There are a number of issues which must be answered for the Federal solar program to be most effective. These issues fall into five categories: strategic Federal issues, issues for specific solar technologies (including organizational issues), solar futures issues, solar-business/labor/public issues, and issues concerning the effects of solar deployment.

Strategic Federal Issues

- What is the relationship between R&D dollars and solar market penetration?
- What is the best strategy for reducing product costs for each solar technology?
- What changes should be made in program strategy for various desired outputs in 1985?
- How many years are saved (or lost) by increasing (or reducing) various aspects of the solar budget?
- What would the solar program look like if it were not budget-limited?
- What are the critics saying about the Federal solar program? How valid are their points? What are the implications for the future direction of the program?
- How would a Federal policy opposing such major energy alternatives as the breeder reactor, oil shale, coal gasification, etc. affect the attitude of energy companies toward solar?
- How would a Federal policy of encouraging solar deployment overseas affect solar use in this country?
- What is the national benefit (if any) of a Federal policy encouraging plants which can be deployed flexibly, vis-à-vis labor and capital intensiveness, time horizon, number and size, etc.?
- How would Federal encouragement of bank loans for solar investments affect solar commercialization?
- Is the Federal program adequate to develop a plausible decentralized scenario?
- How would the public respond to Federally mandated solar decentralization (or centralization)?
- Does the present national solar program adequately support "appropriate" technology?
- If the decision is made to rapidly accelerate solar commercialization, what should be the mechanism(s) for educating the America people?

Issues for Specific Solar Technologies

- What constraints are placed on solar deployment by the lack of low-cost storage?
- What is the ultimate contribution (and how) for solar sources in the transportation sector? Is the present solar program adequate?
- What is the present market for $0.50/$W_p$ photovoltaics? in 1985? How can various Federal strategies affect the latter?
- Is the DOE-postulated biomass market which focuses on three areas (waste, surplus, and dedicated areas) reasonable?
- Are there suitable markets for OTEC power? How can these markets be activated?

Solar Futures Issues

- What is the maximum and/or likely solar contribution in 1985? What level of Federal expenditures would achieve these futures?
- How much solar-produced energy is possible in 2000?
- How much will solar energy in its delivered forms (thermal, fluid, and electric) cost in 2000?
- What are plausible solar futures?
- On what time scale can solar energy be truly competitive, for various future scenarios?

Solar-Business/Labor/Public Issues

- What should be the role of electric (and other) utilities in developing solar energy? Should there be any prohibition of involvement?
- Should there be any constraints on solar involvement by companies engaged in producing energy from other sources?
- Are there any unexplored solar ownership options which could accelerate solar deployment?
- Is solar deployment limited by technical labor capabilities or availability?
- How might public opinion restrict or accelerate solar deployment?
- What is the effect of the high first cost of solar on public support for its deployment?

The Policy Framework

The NEP's ten principles include three which address the framework in which Federal energy policy is to be made. Two are very closely related: principle #1 propounds the need for comprehensive Federal action (and for public awareness and sacrifice), and principle #8 calls for Government policy to be certain. Principle #7 asserts that energy prices should reflect replacement costs.

FEDERAL RESPONSIBILITY (PRINCIPLE #1)

"THE ENERGY PROBLEM CAN BE EFFECTIVELY ADDRESSED ONLY BY A GOVERNMENT THAT ACCEPTS RESPONSIBILITY FOR DEALING WITH IT COMPREHENSIVELY,[38] AND BY A PUBLIC THAT UNDERSTANDS ITS SERIOUSNESS AND IS READY TO MAKE NECESSARY SACRIFICES."

Solar Issues

- What is the level of past and present Federal subsidization of other energy sources?[39] What is the appropriate level of solar subsidization, given these other subsidies?[40]

- What are the costs, benefits, risks, and feasibility of (a) intensive social influence planning; and (b) all-out mobilization as strategies for solar diffusion? What is the possible correlation to past Federal efforts to mobilize various industries?

- What is the present state of awareness about energy/solar energy among the American people? How is that awareness shaped? What can be done to alter it?

POLICY CERTAINTY (PRINCIPLE #8)

"BOTH ENERGY PRODUCERS AND CONSUMERS ARE ENTITLED TO REASONABLE CERTAINTY AS TO GOVERNMENT POLICY."[41]

Solar Issues

- Given that one of the greatest obstacles to widespread solar commercialization is the uncertainty of its present and future technology and economics, what can the Federal Government do to insure that its own solar policies at least are clear and certain?

REPLACEMENT COST PRICING (PRINCIPLE #7)

"ENERGY PRICES SHOULD GENERALLY REFLECT THE TRUE REPLACEMENT COST OF ENERGY."

Solar Issues

- How should "replacement costing" be defined? Should it include only market costs or should it include social costs as well?

- How would replacement cost pricing affect sales of solar energy systems? To what extent does less-than-replacement cost pricing of oil and/or gas lessen demand for solar?[42,43]

CONGRESSIONAL ACTION ON ENERGY LEGISLATION

The Congressional problems afflicting President Carter's National Energy Act (the actual legislation to implement the NEP) have been well documented; there is no need to detail them here. At the present time (March 1978), the legislation is in two conference committees (one on tax and one on nontax measures). Tentative agreement has been reached on three major issues. Briefly, the conference committees have agreed on a coal conversion plan that is quite similar to the President's; they have weakened utility rate reform by requiring only that the states consider, not enact, certain reforms; and they have passed a number of conservation measures, although not all those originally requested. Issues of energy (especially oil) taxation and natural gas pricing remain unresolved.

Although major sections of the NEP have been highly controversial, both the House and Senate easily passed several provisions aimed at increasing solar use. The House version of the National Energy Act (H.R. 8444) includes the following solar measures:

- a maximum $2150 tax credit on expenditures of up to $10,000 for residential solar and wind energy equipment;

- a business energy investment tax credit for solar and other advanced energy technology equipment;

- a three-year, $100 million demonstration of solar heating and cooling systems in Federal buildings;

- a requirement for an energy audit of all Federal buildings, leading to the adoption of solar and energy conservation measures in all buildings by 1990 if such measures will assure maximum possible life-cycle cost-effectiveness;

- a three-year, $39 million Federal procurement of photovoltaic devices, primarily for use by the Department of Defense;

- a 20% increase in the ceiling of insured mortgages through the Federal Housing Administration and the Farmers Home Administration to cover the cost of solar hardware installations;

- grants to states and to public and nonprofit schools and health care facilities to assist in the implementation of solar and energy conservation measures.

Solar measures are also included in several of the Senate's NEP-related bills:

- The Educational and Health Care Facilities Energy Efficiency Act (S. 701) authorizes $900 million over a three-year period for matching grants to schools and hospitals for energy conserving improvements, including solar applications.

- The Energy Production and Conservation Tax Incentive Act provides: (1) a maximum $2200 tax credit for homeowners' purchases of solar equipment, (2) a 15% business energy investment credit, in addition to the 10% credit presently allowed, for qualified solar equipment, and (3) an energy trust fund, to emphasize renewable energy sources.

- The National Energy Conservation Policy Act (S. 2057) contains three solar provisions: (1) a low-interest loan program to be administered by HUD for active and passive applications to residential dwellings; (2) a three-year $100 million program to demonstrate solar heating and cooling in Federal buildings; and (3) a three-year, $98 million program to purchase photovoltaics for use by the Federal Government.

- The Public Utilities Regulatory Policy Act (S. 2114) requires DOE to recommend guidelines to state public utility commissions in order to eliminate rate discrimination or other practices which have adverse effects on alternative energy systems.[44]

By the end of the first session of the 95th Congress, the conference committees had agreed on the following solar provisions:[45]

- a residential tax credit of up to $2200 for solar applications;
- loan programs for residential users of solar systems;
- an investment tax credit for commercial installations of solar equipment;
- grants for solar installations in schools and hospitals;
- a retrofit program for public buildings, and provision of $98 million for the purchase of photovoltaic cells;
- utility rate reform requiring state public utility commissions to consider and adopt, if appropriate, procedures prohibiting discriminatory rates against users of solar systems.

However, House leadership has taken the position that the energy measures must be voted on as a package. Thus, it appears that the solar provisions must wait for conference committee agreement on natural gas pricing and the remaining energy taxation issues.

Notes

[1]Executive Office of the President, *The National Energy Plan* (Washington, D.C.: Government Printing Office, April 1977), pp. 26-27.

[2]Ibid., pp. 28-31.

[3]U.S. President, "National Energy Program [Fact Sheet on the President's Program, April 20, 1977]," in *The President's Energy Program,* a Compilation of Documents printed at the request of Henry M. Jackson, Chairman, Senate Committee on Energy and National Resources, 95th Congress, 1st Session (Washington, D.C.: Government Printing Office, 1977), p. 16.

[4]Ibid.

[5]Ibid.

[6]Energy Research and Development Administration, *A National Plan for Energy Research, Development & Demonstration: Creating Energy Choices for the Future,* ERDA 76-1 (Washington, D.C.: Government Printing Office, 1976), p. 1.

[7]Ibid., p. vii.

[8]The pricing goals of the Ford and Carter Administrations provide a good example of the difference between language and practice. Contrary to their respective goals, the Ford Administration (and many Republicans) was in favor of deregulation of natural gas, which tends to raise the price of gas closer to its replacement cost. The Carter Administration opposes deregulation, at least at the present time.

[9]*"Fact Sheet"* (1977), p. 15.

[10]ERDA 76-1 does include, as one of five goals to guide new energy *technology,* the goal to "protect and improve the Nation's environmental quality by assuring that the preservation of land, water, and air resources is given high priority" (ERDA 76-1 [1976], p. 23). However, it is significant that the goal does not survive in this strong form in the more general national energy goals of the Ford Administration.

[11]Ibid.

[12]*National Energy Plan* (1977), p. XIII.

[13]Ibid.

[14]Although the NEP supports protection of the environment, it is not clear that such protection is compatible with other aspects of the Plan. In speaking of the NEP, Robert Fri, former Acting Administrator of ERDA, charges, "Our energy policy simply lacks the breadth of view to resolve the energy problems compatibly with the environment." ("The Next 25 Years: MOPPS' View of the Future," *The Energy Daily,* November 28, 1977, pp. 5-6.) The biggest conflict between energy production and environmental protection has to do with coal. *Business Week* notes that "On the heels of Carter's energy proposals, the Government imposed a series of tough restrictions on the mining and burning of coal that is likely to prevent some of the demand increases from occurring." One industry analyst noted, "If you want to judge the Carter Administration by what it has done and not by what it has said, you can make a case that it is anti-coal." ("The Gloom in Coal," *Business Week,* November 28, 1977, p. 76.)

[15]The Congressional Research Service (CRS) identifies the environmental problems associated with coal as restoration of mined lands, deterioration of public health due to air pollution, harm to crops from sulfur dioxide and acid rain, and nitrogen oxide pollution. (U.S. Congress, House Committee on Interior and Insular Affairs, *Excerpts from: An Initial Analysis of the President's National Energy Plan,* 94th Congress, 1st Session, June 1, 1977, p. xxiv.) Additional problems have to do with CO_2 emissions (the "greenhouse" effect), the impact on boom towns in the West, and the shortage of water in the West. Also, the NEP's call for 75 additional nuclear plants by 1985 raises the environmental issues of radiation, radioactive wastes, and reactor safety. (Denis Hayes, *Rays of Hope: The Transition to a Post-Petroleum World* [New York: W.W. Norton & Company, Inc., 1977]; also see U.S. Congress, Office of Technology Assessment, *Analysis of the Proposed National Energy Plan* [Washington, D.C.: Government Printing Office, August 1977], pp. 165-67).

[16]The international problems associated with energy are tremendous. The Office of Technology Assessment (OTA) states, "The sense of insecurity attached to the importing of energy resources is magnified by the fact that in most cases supply lines for energy are very long and thus potentially very vulnerable. No nation can be comfortable if a commodity on which its economy depends comes from so unceratin a source. Moreover, in any situation where a state or group of states greatly dependent on imports can assemble a substantial military capability, a disruption or threatened disruption of those supplies carries with it a high risk of international violence. It is noteworthy that the U.S. response to the embargo of 1973-74 included thinly veiled threats of military action. Apart from the direct threat of military violence, uncertainty about supplies and spiralling energy prices threaten to disrupt the stability of many weakened western economies and to dampen the hopes of nations aspiring to raise their standards of living. . . . As the world's largest consumer and importer of energy and acknowledged leader in most energy technologies, the United States will necessarily be the focus of international tensions generated by energy issues. . . . Solar energy is . . . the one energy resource which is reliably available worldwide. To the extent that it can be substituted for conventional energy sources, solar energy could provide a number of nations with the confidence that needed energy would continue to be available in spite of uncertainties in worldwide energy markets." (OTA, *Application of Solar Technology to Today's Energy Needs,* Volume I, prepublication draft, June 1977, p. VII—8-11).

[17]The United Electricians argue that "Low income families currently spend approximately 25% of their incomes on energy. Families with incomes over $24,000 now spend only 4% of their incomes on energy [directly]. It is clear where increases in energy prices are going to hurt the most." ("Carter's Energy Program—Who Will Profit—Who Will Pay?" *United Electricians News,* May 9, 1977, p. 7.) Similarly, the AFL-CIO notes that "For the poor, the effect [of the NEP] could be serious hardship; and, for many middle-income Americans, sharp cutbacks in living standards would occur. But for the wealthy, higher energy costs would mean nothing." (Andrew J. Biemiller, "Statement by Andrew J. Biemiller, Director, Department of Legislation, American Federation of Labor and Congress of Industrial Organizations, before the Committee on Ways and Means, on Tax Aspects of President Carter's Energy Proposals," Unpublished, May 19, 1977, p. 1).

[18]". . . The [solar] credits are available only to taxpayers whose tax liabilities are sufficient to cover the credit claim. . . . Because the credits are more available to middle and upper-income households, they tend to favor homeowners more than renters, and homeowners with significant tax liabilities more than those with little or no tax liability." (U.S. Congress, Congressional Budget Office, *President Carter's Energy Proposals: A Perspective,* Second Edition [Washington, D.C.: Government Printing Office, June 1977], p. 94.)

Also, the University of Texas notes that "The proposed program needs to be more specific . . . as applied to multiple family dwelling, i.e., similar credits per dwelling unit should be available. . . ." "(Gary C. Vliet, "Solar Energy," in *Preliminary Assessment of the President's National Energy Plan* [Austin, Texas: The University of Texas at Austin, May 11, 1977] p. 329.) In other words, the NEP's solar tax credit proposals are biased in favor of the middle and upper classes, homeowners, and single-family home dwellers.

The AFL-CIO suggests that the tax credit program "should be supplemented by a federal low-interest direct loan and loan guarantee program" (Biemiller, "Statement" [1977], p. 4). James Ridgeway and Andrew Cockburn agree that "The only way for the government to introduce solar and other alternative forms of energy in a consistent and large-scale fashion is to make available cheap money for that purpose. This can be done by offering low-cost loans directly to consumers. It can be done by federal guarantees of state and local loans, the proceeds of which would be used for inexpensive loans to consumers. A program of credit application, whereby the controller of the currency and the federal reserve system force banks to channel funds into desirable energy investments could very well be helpful." ("Carter's Powerless Energy Policy," *New York Review of Books,* May 26, 1977, p. 36.)

[19]It may be cheaper for utilities than for individuals to raise capital. The Committee on Nuclear and Alternative Energy Sources (CONAES) claims that ". . . The costs of capital to the energy supply industry are much lower than the costs of capital to most energy users. Consumer loans are often more than double rates available to utilities." (*Draft Report of the Panel on Demand and Conservation* [February 1977], pp. X-4,5) Hayes says that ". . . credit criteria systematically channel capital to big projects (like power plants) rather than to small ones (like home insulation) . . ." (Hayes, *Rays* [1978], p. 87). But the most commercially ready solar applications, residential water and space heating, are appropriate primarily to the individual. Thus, in effect, solar may face discrimination in the capital market.

[20]While most analysts applaud conservation, some believe that the NEP does not ask enough. OTA notes that "Because of the likelihood of supply shortfalls, stronger conservation goals may be necessary." (OTA, *Analysis* [1977], p. 1.) Similarly, "[The General Accounting Office] is concerned that the conservation initiatives in the Administration's plan are too modest." (General Accounting Office, *An Evaluation of the National Energy Plan* [Washington, D.C.: Government Printing Office, July 25, 1977], p. iv.) GAO adds that the Plan ". . . relies too much on voluntary actions in some areas." (ibid.) CRS agrees: "Voluntary conservation standards for buildings are emphasized, but it is not clear whether voluntary measures alone are enough to achieve the desired savings." (CRS, *Excerpts* [1977], pp. xi-xii.) Some analysts question whether conservation is, in fact, the NEP's "cornerstone." Thus, GAO believes, "The major impact of the plan, as proposed, seems to be reducing oil imports by shifting to coal rather than by conserving energy." (GAO, *An Evaluation* [1077], pp. 2-3.) OTA agrees: "The Plan relies more on industries shifting from oil to coal than it does on conservation as a means of holding down oil imports." OTA, *Analysis,* [1977], p. 13.)

[21]*National Energy Plan* (1977), p. xiii.

[22]For example, the National Association of Manufacturers (NAM) believes, "The President relies far too much on energy *conservation* and too little on energy *supply*." (National Association of Manufacturers, "Guidelines for Action on: President Carter's Energy Proposals," May 27, 1977, p. 1). Similarly, the *Power Engineering Society Newsletter* charges that "... we appear to be on a course of forced conservation.... Objectives would be better achieved by preserving incentives for investment and improving climates for capital formation." ("The Energy Plan—Overly Complex," *Power Engineering Society Newsletter,* October 1977, p. 1). W. Donham Crawford, President of Edison Electric Institute, agrees: "Conservation is not a solution to the problem in the sense that technology is.... The energy problem is essentially ... quite simple—we are running out of gas and oil and haven't yet developed anything really new that can completely take their place." (W. Donham Crawford, "Plenty of Energy: It's Everything Else That's Short," *Government Executive,* October 1977, p. 20.)

[23]*National Energy Plan* (1977), p. xiii.

[24]Ibid., p. 96.

[25]Ibid., p. xiii.

[26]The goal of coal production may not be met. Following is a table of the predicted shortfall in coal use by 1985:

	Shortfall (million tons/ year by 1985)
CBO (*A Perspective* [1977], p. xviii)	50
GAO (*An Evaluation* [1977], p ix)	more than 200 (if air quality standards are met)
OTA (*Analysis* [1977], p. 3)	up to 200
Naill and Backus	100

(Roger F. Naill and George A. Backus, "Evaluating the National Energy Plan," *Technology Review,* 79:8, July/August 1977, p. 4)

All of the above, plus The Petroleum Industry Research Foundation (PIRF) ("U.S. Oil Supply and Demand to 1990," unpublished, October 1977, p. 2), agreed that the shortfall will be due to insufficient demand. Industrial usage is felt to be unlikely to be sufficient to meet Carter's goal.

[27]Nuclear power may not be as bountiful as hoped in the NEP. OTA predicts a possible shortfall of 15% by 1985 (0.6 million barrels of oil equivalent [BOE] per day) (OTA, *Analysis* [1977], p. 51). GAO states that the administration's goal of quadrupling nuclear energy by 1985 "... is highly unrealistic.... It would require that by 1985 all 77 nuclear power plants now licensed for construction be completed and that all nuclear power plants would have to be operated at an average annual capacity of 69%." (GAO, *An Evaluation* [1977], p. iii). The University of Texas adds that "There is serious question if the production goals for ... nuclear can be attained." (W.W. Rostow, William L. Fisher, and George Kozmetsky, "The National Energy Plan: An Overview, in *"Preliminary Assessment of the President's National Energy Plan* [Austin, Texas: The University of Texas at Austin, May 11, 1977], p. 20.)

[28]*National Energy Plan* (1977), p. xiii.

[29]Ibid., p. xii.

[30]Ibid., pp. xxii, 75.

[31]Ibid.

[32]Ibid., pp. 43,76.

[33]Ibid, pp. xvi, 46,76.

[34]Ibid., p. 76.

[35]Ibid., p. 88,

[36]Ibid.

[37]Ibid., p. 81.

[38]Most reviews agree that a strong Federal role is necessary, but some question whether the NEP provides such leadership. For example, the GAO states that "we believe [the NEP] is moving in the right direction, but unfortunately is not strong enough to meet many of its objectives." (GAO, *An Evaluation* [1977], p. 2-1.)

[39]For one analysis of subsidies to other energy sources, see Energy Research and Development Administration, Division of Solar Energy, *An Analysis of Federal Incentives Used to Stimulate Energy Production,* prepared by Battelle Pacific Northwest Laboratories, draft, September 1977.

[40]The issue of subsidization goes beyond historical and present subsidies to other energy sources. As the AFL-CIO says, "There is no free market in energy pricing." ("The Energy Program: A Critical Look," *The AFL-CIO American Federationist,* May 1977, p. 11.) Recognition that the energy marketplace does not operate according to competitive rules opens the door to include in pricing such considerations as environmental costs, employment, national security, critical materials, interest groups affected, political feasibility, equity, and energy savings, to name only a few. Such considerations can also be included in investment decisions. For example, the University of Texas notes that "The conventional payback analysis [of investment decisions] ... does not capture the effect that President Carter properly emphasized that we have only a short period to become less dependent on foreign oil and gas" (George) Kozmetsky and Eugene B. Konecci, "National Energy Plan and Investment Analysis," in *Preliminary Assessment of the President's National Energy Plan* [Austin, Texas: The University of Texas at Austin, May 11, 1977], p. 338.) To the extent such social costs are higher for other energy sources, their inclusion will help solar energy growth.

[41]The NEP's coal policy is not certain. On one hand, it calls for increased coal production by 1985, to a total of more than 1 billion tons per year; on the other hand, its environmental policies may drastically weaken demand for coal (see *National Energy Plan* [1977], sections 3,9).

The position on nuclear is also unclear. In April, President Carter called it a "last resort"; in his November speech to the nation he failed even to mention it. Thus, some reviewers see nuclear as a minor part of the Plan. The University of Texas says that "The program does not place emphasis on ... nuclear power usage." (Hal B.H. Cooper, Jr., "Analysis of the Environmental Implications of President Carter's Proposed National Energy Plan," in *Preliminary Assessment of the President's National Energy Plan* [Austin, Texas: The University of Texas at Austin, May 11, 1977], p. 279). CRS agrees: "The Plan reflects the President's view that nuclear energy should be the energy source of last resort." (CRS, *Excerpts* [1977], p. xvi.) But the NEP calls for more than doubling the number of nuclear plants—adding 75 to the existing 39—by 1985, leading others to view nuclear power as a major component. Thus the GAO notes, "The administration plan's ... second objective [for nuclear power, besides dealing with the plutonium economy] amounts to greatly increasing the use of present generation nuclear power plants." (GAO, *An Evaluation* [1977], p. x.) The *Wall Street Journal* reports that "... [President Carter's] energy proposals envision heavy reliance on nuclear power plants. In the months since he's taken office, the President has done an about-face—so much so that he might well be viewed as a closet advocate of nuclear power." (Les Gapay, "The Turnabout on Nuclear Policy, "*Wall Street Journal,* October 19, 1977, p. 22.) Barry Commoner charges that "[the Plan] is a decision to go nuclear disguised as a conservation program." ("SIPI 1977 Annual Meeting: Focus on National Energy Policy," *SIPISCOPE,* Scientists' Institute for Public Information, May/June 1977, p. 1.) Also, there is an apparent ambiguity in supporting many new nuclear plants while vetoing the Clinch River Breeder Reactor. OTA notes that "if nuclear power is to be a long-term option, some sort of breeder, or near breeder ... will be necessary." (OTA, *Analysis* [1977], p. 61)

[42]Some sources believe that the NEP does not mandate true replacement costs for all fuels, notably natural gas. Walter J. Mead states, "The President notes that oil and gas are now priced below their 'marginal replacement cost'.... [T]his is a true statement... . However his policy recommendations [for natural gas] perpetuate the very problem that he has so well defined." ("An Economic Appraisal of President Carter's Energy Program," *Science,* July 22, 1977, p. 341).

[43]Several analyses doubt that the NEP pricing will bring forth as much additional oil and gas as the Plan expects. The GAO estimates that 1985 natural gas production will fall short of the Plan's expectation by 1 million barrels of oil equivalent/day. (GAO, *An Evaluation* [1977], p. 4.19.) The OTA believes the gas shortfall could be between 1 to 1½ million barrels of oil equivalent/day; it estimates that the oil shortfall will be the same. (OTA, *Analysis* [1977], p. 30.)

[44]Glen Moore, "Solar Energy Legislation in the 95th Congress," Memo prepared by the Congressional Research Service, October 13, 1977.

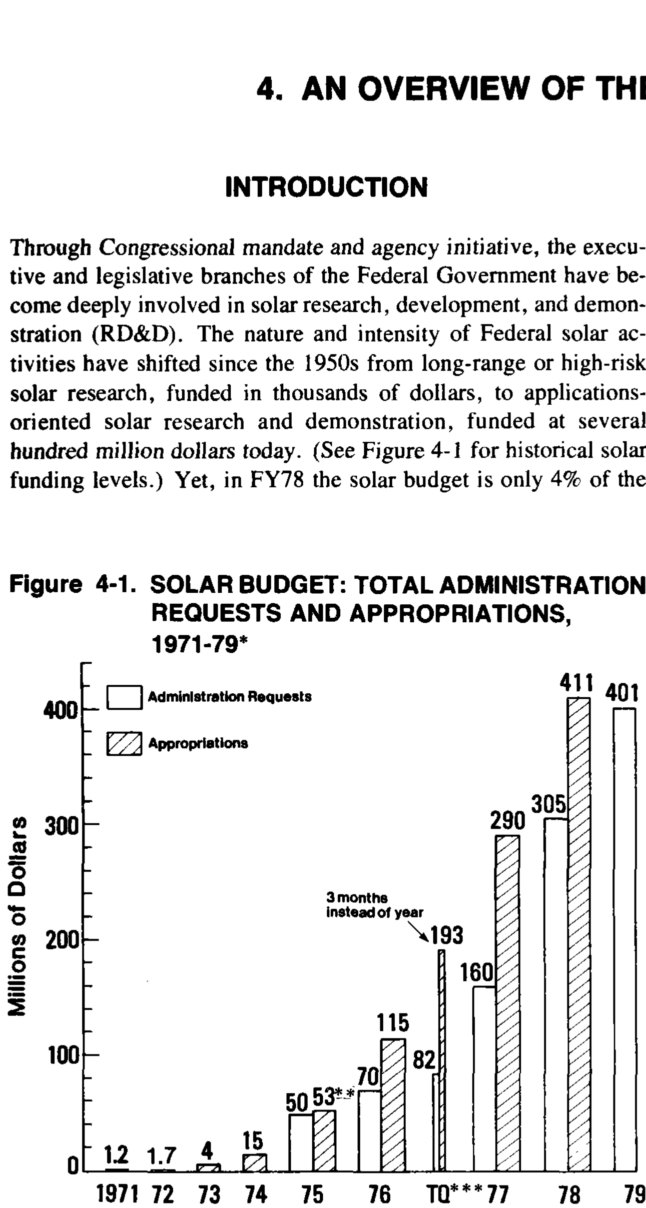
[45]Allen Howe, "Confreres on Solar," *Solar Engineering,* December 1977, p. 27; also see "Conference Action on the Solar Provisions of the National Energy Act," Memo prepared by the Environmental Study Conference, December 1977.

4. AN OVERVIEW OF THE FEDERAL SOLAR PROGRAM

INTRODUCTION

Through Congressional mandate and agency initiative, the executive and legislative branches of the Federal Government have become deeply involved in solar research, development, and demonstration (RD&D). The nature and intensity of Federal solar activities have shifted since the 1950s from long-range or high-risk solar research, funded in thousands of dollars, to applications-oriented solar research and demonstration, funded at several hundred million dollars today. (See Figure 4-1 for historical solar funding levels.) Yet, in FY78 the solar budget is only 4% of the Department of Energy's budget and less than one-thousandth of the total Federal budget. See Figure 4-2.) Most of the early solar activity took place at the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA), but several cabinet level departments, Congress and its information sources, Federal agencies, and the national laboratories now have active interests in solar RD&D. This chapter will describe the role of Federal participants in solar RD&D and will review critiques of the Federal solar effort.

Figure 4-1. SOLAR BUDGET: TOTAL ADMINISTRATION REQUESTS AND APPROPRIATIONS, 1971-79*



*Administration requests available only for FY75-FY79; appropriations not yet made for FY79.

**Also reported as 48.9.

***Transition quarter between FY76 and FY77; bars show what funding would have been if it had been for a full fiscal year.

Source: Data from DOE; U.S. Congress, House of Representatives; Committee on Nuclear and Alternative Energy Systems (CONAES); National Science Foundation (NSF/RANN); SRI International.

DESCRIPTION OF THE FEDERAL SOLAR ENERGY PROGRAM

U.S. Congress

The U.S. Congress provides the legislative framework and final budget for Federal solar energy activities. Conceptualization and drafting of solar-related legislation occur in many House and Senate Committees/Subcommittees. (See Table 4-1.) Figure 4-3 shows the solar budget process which begins at OMB and finally becomes law when signed by the President. Congress is advised by the Office of Technology Assessment (OTA) which helps legislative policymakers anticipate and plan for the consequences of technological changes. Since its creation in 1974, OTA has had a continuing involvement in solar technology assessment. Other Congressional sources of information are the Congressional Research Service of the Library of Congress (CRS/LOC), the General Accounting Office (GAO), and the Congressional Budget Office (CBO).

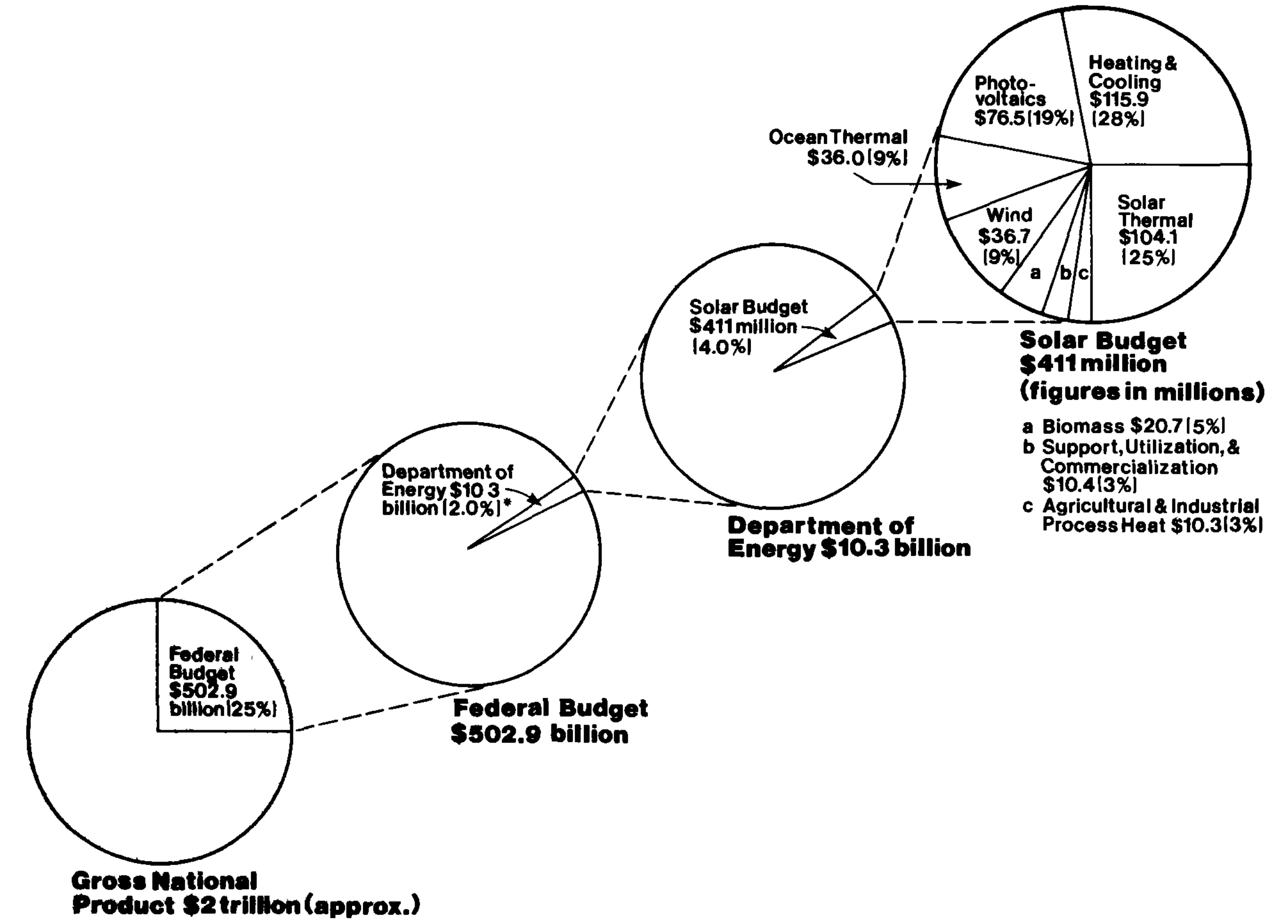
Executive Branch

DEPARTMENT OF ENERGY

Until 1977, the bulk of Federal efforts aimed at solar deployment was carried out by ERDA, HUD, and FEA. After passage of the Department of Energy Organization Act, the solar functions previously vested in ERDA and FEA were transferred to DOE. DOE now has responsibility for the following solar activities:[1]

- development and implementation of programs and policies to encourage widespread use of solar energy;

Figure 4-2. SOLAR BUDGET IN RELATION TO ENERGY AND FEDERAL BUDGETS AND TO GROSS NATIONAL PRODUCT, FY78



*The DOE budget does not include supplemental appropriations, but the solar budget does. This follows the DOE "Budget Highlights" for FY79.

- consultation with representatives of science, industry, environmental organizations, and consumers interested in solar energy;
- development of mechanisms for the effective participation of state and local governments in the resolution of solar energy problems;
- research, development, and demonstration of solar energy technologies;
- determination of the solar energy resource base; and
- coordination of solar energy information dissemination efforts.

Figure 4-4 highlights the organizational location of DOE's solar-related activities. Although the Office of the Assistant Secretaries for Conservation and Solar Applications (CS) and Energy Technology (ET) are the focal points of solar efforts, many other offices and divisions contribute to the Federal solar program. In FY77 the Materials Science Program (now in the Office of the Director for Energy Research) funded about $2 million in research areas related to solar energy.[2] The Office of the Assistant Secretary for Environment conducts solar environmental R&D, reviews DOE policies and strategies for environmental impacts, and prepares policy and legislative environmental impact statements. Solar policy is recommended by the Office of the Assistant Secretary for Policy and Evaluation. The Energy Information Administration collects, analyzes, and disseminates solar information. In one way or another almost all of DOE has a role in the solar program.

DOE's solar functions are distributed between CS and ET on the basis of technology development status. Solar technologies which are considered mid- to long-term energy supply strategies (solar thermal, photovoltaics, wind energy, biomass, and ocean thermal) are located in ET, and presently demonstrable technologies (solar heating and cooling, plus agricultural and industrial process heat) are situated in CS.

The general objectives of the Assistant Secretary for Energy

Table 4-1. CONGRESSIONAL COMMITTEES/SUBCOMMITTEES WITH JURISDICTION OVER SOLAR ENERGY LEGISLATION

Solar Interests	Committees of House of Representatives	Senate
Solar applications in agriculture	Agriculture (Subcommittee on Conservation and Credit)	Agriculture and Forestry
Appropriations	Appropriations (Subcommittees on Housing and Urban Development and Independent Agencies and on Public Works)	Appropriations (Subcommittees on Housing and Development and on Public Works)
Solar applications in housing and financial incentives for solar	Banking, Currency, and Housing (Subcommittees on Economic Stability, Housing and Community Development, and on International Trade, Investment, and Monetary Policy)	Banking, Housing, and Urban Affairs (Subcommittees on Housing and Urban Affairs and on Small Business)
Energy policy legislation; consumer protection and consumer affairs	Interstate and Foreign Commerce (Subcommittees on Consumer Protection and Finance, on Energy and Power, and on Oversight and Investigation)	
Solar applications in public buildings and grounds	Public Works and Transportation (Subcommittee on Public Buildings and Grounds)	Environment and Public Works
DOE energy R&D policy and funding	Science and Technology (Subcommittee on Energy Research, Development, and Demonstration)	Energy and Natural Resources
Protection and assistance to small solar businesses; consideration of incentives to encourage use of solar equipment by small businesses	Small Business (Subcommittees on Energy and Environment and on SBA and SBIC Legislation)	Small Business
Solar tax incentive legislation	Ways and Means (Subcommittee on Trade)	Finance (Subcommittee on Energy)

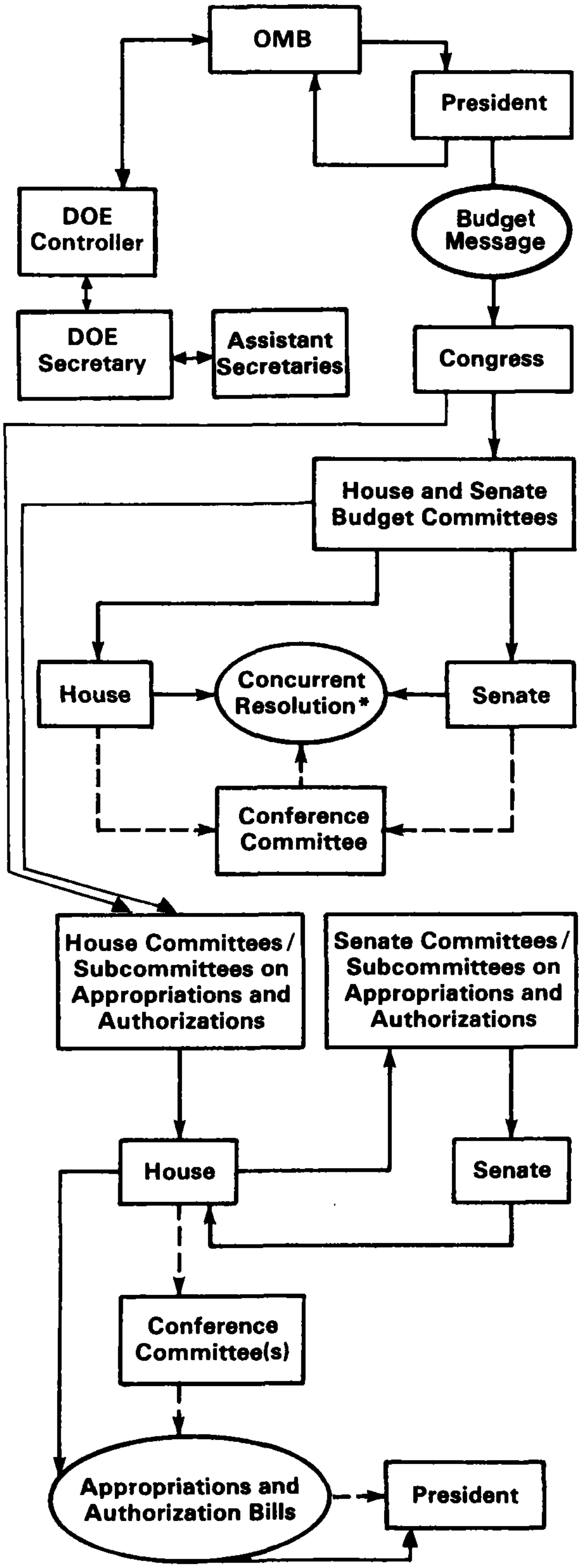
Technology are to develop mid- and long-term technology development strategies, provide energy technology information, and implement energy programs. Among the principal current and planned ET programs are:

- construction of a 10 MW_e central receiver power plant to test, demonstrate, and produce solar-generated electricity;
- major procurement of photovoltaic systems and continued research into system cost reduction;
- continued development of both small wind machines and large-scale, multi-unit wind systems;
- conversion of the Hughes Mining Barge into an ocean thermal energy conversion test facility.[3]

The determination of the internal organization of CS has been delayed by the late nomination of an Assistant Secretary. However, solar programs proposed in the FY 79 budget include:

- technology development in support of the Solar Heating and Cooling Demonstration Program;
- final cycle of solar cooling demonstrations as well as maintenance and evaluation of earlier demonstration cycles;

Figure 4-3. SOLAR BUDGET PROCESS



*The concurrent resolution sets forth the level of total budget outlays and total new budget authority as well as an estimate of outlays and authority for each major functional area.

- initiation of 75-125 additional Federal buildings projects;
- studies and experiments to identify commercialization barriers and formulate market incentives and strategies;
- continuation of standards development, certification, training, information gathering, and public information activties.[4]

The Solar Energy Research Institute and Regional Network as well as the national laboratories currently report to various parts of DOE. In addition, DOE administers the new Energy Extension Service and State Energy Conservation Planning programs. Both programs are ultimately directed toward conservation and substitution of renewable for nonrenewable fuels, so solar subprogram elements are emerging.

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

Although some energy-related functions of HUD were transferred to DOE, HUD will retain joint management with DOE of residential solar heating and cooling demonstrations. (Responsibility for commercial and industrial demonstrations lies with DOE.) Designed to investigate the practical application of solar heating and cooling, the overall demonstration program has five major elements:[5]

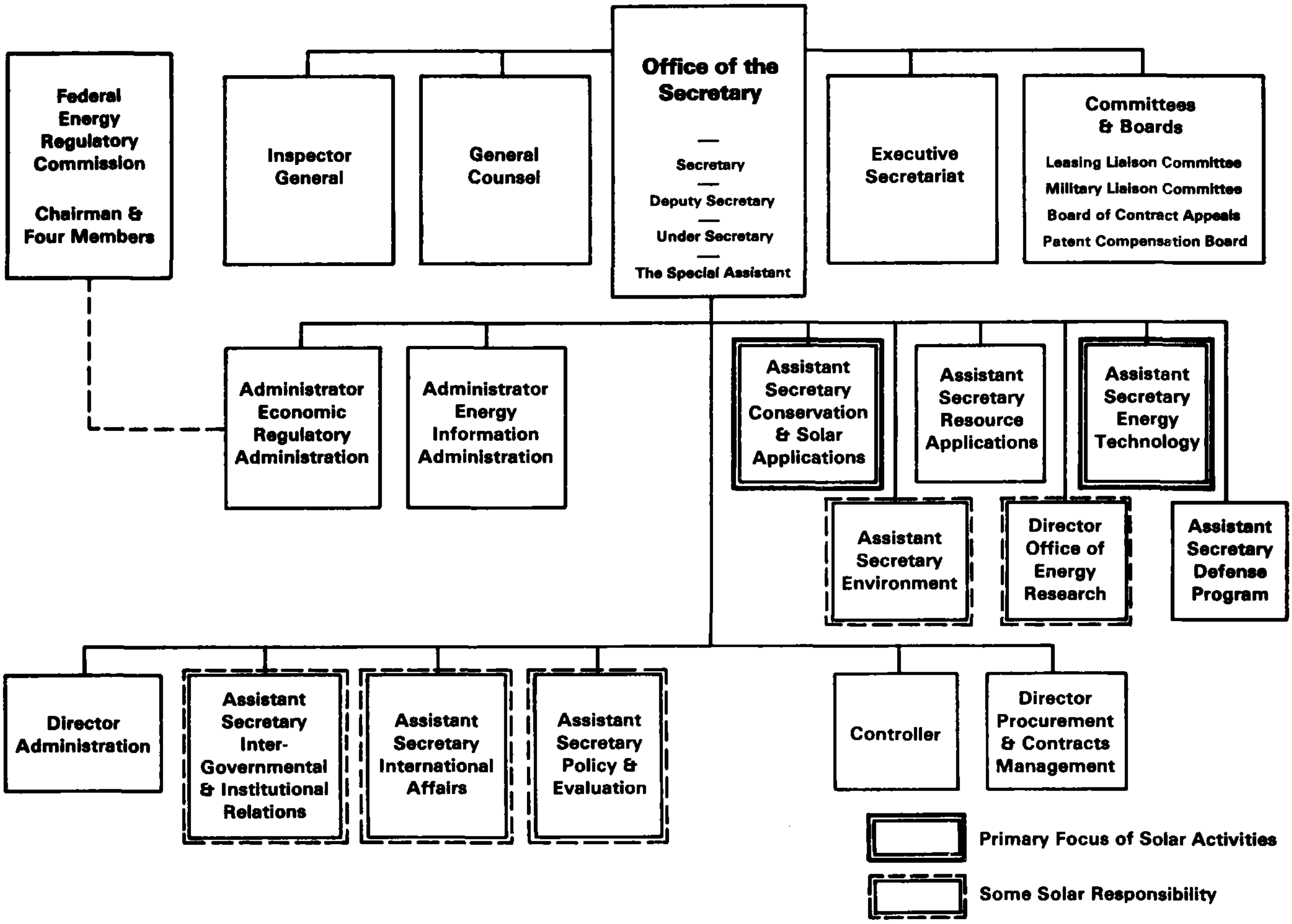
- demonstrations of solar technology;
- development of solar technology to support such demonstrations;
- R&D of advanced heating and cooling technology for possible use in later stages of the demonstration;
- development of standards and certification procedures for solar energy systems;
- dissemination of solar information.

DEPARTMENT OF COMMERCE

Two agencies of the Department of Commerce support the Federal program. The Center for Building Technology of the National Bureau of Standards is developing a set of performance criteria for solar energy equipment and residential dwellings; is monitoring the design, testing, evaluation, construction, and operational phases of the DOE and HUD demonstration programs; and is developing intermediate standards for solar heating systems. The National Oceanic and Atmospheric Administration will develop and carry out a plan for the inventory of all forms of solar energy resources associated with Federal lands.

The Commerce Department also coordinates the nine Title V Commissions set up by the Public Works and Economic Development Act of 1965 for regional economic development and job creation. To accomplish these ends the Title V Commissions provide technical assistance and funds for planning, research, demonstration projects, and training programs; some of these projects are advancing the use of solar energy.

Figure 4-4. ORGANIZATION OF DOE'S SOLAR-RELATED ACTIVITIES



DEPARTMENT OF DEFENSE

The Department of Defense (DOD) is coordinating the installation of solar heating and cooling systems in Federal buildings (in accordance with requirements of PL 93-409). At the same time, DOD is providing sites for solar electric applications where they satisfy military needs and are competitive with conventional systems.

DEPARTMENT OF AGRICULTURE

The Department of Agriculture (DOA) manages agricultural aspects of the Agricultural and Industrial Process Heat Program. Through the Agricultural Research Service, DOA has mounted an R&D effort in agricultural applications of solar. The Food and Agriculture Act of 1977 would significantly expand this DOA activity, depending on passage of an appropriations bill. New programs defined by the Act include:[6]

- a Competitive Grants Program for carrying out R&D related to the uses of solar energy for farm buildings, homes, and machinery;
- a Solar Energy Research Information System which will annually compile solar energy research projects related to agriculture;
- the Model Farm Program which will establish at least one model farm per state to demonstrate solar energy projects;
- the Demonstration Program which will extend applications of selected model farm solar projects to operating farms within each state;
- three to five Regional Solar Energy Research and Development Centers which will perform agricultural research, extension work, and demonstration projects related to the agricultural use of solar energy.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Pending NEA legislation could expand the Department of Health, Education and Welfare's (HEW) solar role. Should Congress pass an educational and health care facilities energy efficiency provision in the NEA, HEW will become manager of a three-year, $900 million program of matching grants to public or nonprofit schools and hospitals for energy conserving (including solar) improvements in their facilities. Meanwhile, HEW will continue to consult in the program design and management of commercial solar demonstration systems, in the development of interim performance criteria and monitoring processes, and in the collection and dissemination of solar energy information to consumers.

DEPARTMENT OF INTERIOR

The Department of Interior participates in solar deployment through solar demonstrations in its buildings if such systems are economically competitive. Furthermore, the Bureau of Reclamation conducts solar research by mandate of the Public Works Appropriations Act of 1975 which allocated funds for a Western Energy Expansion Study. That study identified and evaluated opportunities (including solar) for increased electric power generation in 17 Western states. The Bureau is now conducting a preliminary screening survey to determine sites for marketable wind power. Another Bureau interest is the potential of solar power systems to run desalination plants and remote pumping stations.

DEPARTMENT OF STATE

The Department of State has responsibility for negotiating international agreements on bilateral or multilateral RD&D projects and on potential large scale export of commercial solar energy products. The International Development and Food Assistance Act of 1977 broadens the State Department's role in solar development. Section 119 authorizes:[7]

- the President to furnish cooperative programs with developing countries in energy conservation and production, with particular emphasis on programs in R&D and use of small scale, decentralized, renewable energy sources for rural areas;

- the President to carry out studies to identify the energy needs, uses, and resources which exist in developing countries;

- the Agency for International Development (AID), in cooperation with DOE, to conduct a review of the options for implementing the purposes of this section, one of which shall be a proposal for a nonprofit Government corporation (which would be designated the International Energy Institute).

Through the Agency for International Development (AID), the Department of State also influences international solar deployment. Established to assist with the augmentation of human and economic resources, AID has recognized the need for decentralized energy programs for rural development. New programs of this nature include assessment of food/fuel interactions, training programs, and demonstration projects.[8]

IPTASE

The Interagency Panel on Terrestrial Applications of Solar Energy (IPTASE) was established four years ago as an informal communications medium for Federal agencies with an interest in solar energy. IPTASE provides a forum for solar coordination discussion, and review.

Executive Office of the President

OFFICE OF MANAGEMENT AND BUDGET

The Office of Management and Budget (OMB) plays a crucial role in the solar budgeting process. (See Figures 4-3.) OMB assists the President in budget preparation, then later supervises and controls administration of the approved budget. OMB also assists the President by assessing program objectives, efficiency, and performance; by clearing and coordinating departmental advice on proposed legislation; and by promoting improved plans of administration management.

OFFICE OF SCIENCE AND TECHNOLOGY POLICY

This office advises the President on scientific and technological issues; evaluates the Federal effort in science and technology; assists the President, OMB, and Federal agencies throughout the budget process; and aids the President in providing leadership to and coordination of Federal R&D programs.[9]

ENERGY RESOURCES COUNCIL

The Energy Resources Council is chaired by the Secretary of DOE. Among the other council members are representatives of OMB, GSA, NSF, and CEQ. The Council facilitates interagency communication and presents consistent energy policy recommendations to the President.[10]

COUNCIL ON ENVIRONMENTAL QUALITY

CEQ, composed of three Presidential appointees, is responsible for developing and recommending to the President national policies which enhance environmental quality. Additional responsibilities include: (1) continuing analysis of trends in the human environment, (2) administration of the environmental impact statement process, (3) ongoing assessment of energy R&D from an environmental standpoint, and (4) preparation of an annual environmental quality report to Congress.[11]

Other Federally Funded Agencies

SERI

SOLAR ENERGY RESEARCH INSTITUTE AND THE SOLAR REGIONAL NETWORK

SERI, which began operations July 1, 1977, is mandated to perform such research, development, and related functions as the DOE Secretary may deem necessary or appropriate. Operated much like a national laboratory—Federal funding and private management—SERI's mission is to accelerate the commercialization of solar energy.

In March 1978, DOE concluded a three-month study of the respective roles of SERI and the regional centers. As a result, DOE has decided that National SERI will have the principal responsibility for the management and performance of assigned solar RD&D programs and projects; for planning support to national solar energy policies, program plans, and strategies; and for international solar technology programs. Furthermore, SERI will perform market analyses and assessments of economic, environmental, social, and institutional barriers to the national and international introduction of solar technologies. In line with its national RD&D responsibilities, National SERI must also assure that duplicate Federal activities are identified and that R&D carried out by the regional solar centers is consistent with national planning. National SERI will report to the Assistant Secretary for Energy Technology.

At the March 1977 announcement of the SERI site selection, ERDA revealed plans for four regional implementation centers. The states organized themselves under these coordinating organizations: Northeast Solar Energy Center, Cambridge, Mass.; Mid-American Solar Energy Complex, Eagan, Minn.; Western Solar Utilization Network, Portland, Oreg.; and Southern Solar Project Committee, Atlanta, Ga.

The regional solar centers will be responsible for the regional commercialization of solar technologies and for energy conservation integral to solar applications. Assignments related to the fulfillment of this mission will come from th e Assistant Secretary for Conservation and Solar Applications. Solar R&D projects also may be undertaken by the regional centers, but such projects would first pass through National SERI.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA's field centers will continue to fulfill their interagency agreements (once with ERDA, now with DOE) as follows:

- The Marshall Space Flight Center in Huntsville, Alabama, provides support to the solar heating and cooling demonstration program; that support includes the development, testing, and evaluation of components, subsystems, and systems.

- The Lewis Research Center (LRC) is developing, testing, and evaluating wind energy components, including a 100 kW (133 hp) wind turbine. LRC also operates the photovoltaics system test facility and assists the DOE Photovoltaic Conversion Program through project planning and management.

- The Jet Propulsion Laboratory (JPL) of the California Institute of Technology is managing the Low Cost Silicon Solar Array Development Program. Furthermore, JPL performs R&D activities supporting the DOE thermal power systems program and assists DOE with the planning, implementation, and evaluation of a 1 MW small community solar application.

NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) through its Research Applied to National Needs Program, began the first concerted solar research effort in the early 1970s. That program and the NSF staff assigned to it were transferred to ERDA in 1974 by PL 93-577. Although NSF no longer has an explicit role in solar research, it continues to support the Federal solar program through long-term, basic, scientific research; the promotion of international cooperation through science; and development and implementation of science education programs.

NATIONAL LABORATORIES

Most energy technology laboratories are also involved in some aspect of solar R&D. Table 4-2 shows estimated 1978 solar budget and staff, plus the general nature of solar activities for each of those labs.

TENNESSEE VALLEY AUTHORITY

The Tennessee Valley Authority has allocated $7.7 million to solar energy research in 1978. Three of the major research projects are: (1) a feasibility study on the addition of a wood-fired plant to the TVA system; (2) an assessment of industrial and commercial process heat requirements within TVA's jurisdiction, with a corresponding analysis of the potential of concentrating collectors, photovoltaics, and wind energy for meeting those requirements; and (3) an analysis of options for making solar heating and cooling of buildings practical and popular in the TVA area.

TVA is also planning two major solar demonstrations. Thomas Village, in southwestern Virginia, is a voluntary relocation project for people now located on a nearby flood plain. TVA is spending $2.9 million to purchase land and develop the site and has applied for a HUD grant to demonstrate solar heating in 30 units of the village. The second demonstration project will be a village for construction workers who are building the Yellow Creek Nuclear Power Plant in northern Mississippi. Housing in the village will be designed to include proper insulation, solar energy, and new methods of waste disposal. Once the power plant is completed, the construction village will be converted to a permanent recreation facility.

NATIONAL CENTER FOR APPROPRIATE TECHNOLOGY

In 1976 the Community Services Administration (CSA) created the National Center for Appropriate Technology (NCAT) as a nonprofit, tax-exempt corporation which provides technical assistance and small grants for low-income, appropriate technology projects. Grant categories include dissemination, development, and demonstration; education; training; research; and evaluation.

GSA, USPS, AND OTHER AGENCIES

A common form of solar activity is the use of solar equipment in buildings where such systems are economically competitive. Federal agencies also lend support by consulting on various aspects of the National Solar Program. Among the agencies cooperating in this fashion are the General Services Administration and the U.S. Postal Service.

Table 4-2. SOLAR ACTIVITIES OF THE NATIONAL LABORATORIES

	Ames	Argonne	Brookhaven	Idaho	Lawrence Berkeley	Lawrence Livermore	Los Alamos	Pacific Northwest	Sandia
Estimated 78 Solar Budget ($M)	0.32	5.4	1.4	—	1.1	1.35	2.4	17.6	21.8
Estimated 78 Solar Staff (FTE)	5	137	40	—	23	31	41	74	316
Materials	X				X		X	X	
Photovoltaics	X				X			X	X
OTEC		X						X	
Bio/Chemical Conversion					X			X	
Passive					X		X		
Thermal Conversion		X	X	X	X	X	X		X
Systems Analyses		X			X	X	X		X
Storage						X			
Wind								X	X
Total Solar Energy									X
Resource Assessment			X		X			X	
Information, Education, and International Programs									
Policy Analysis			X		X	X	X	X	
Economics and Marketing Analysis								X	
Institutional and Environmental Analysis			X		X				
Program Assessment				X	X	X			
Technology Transfer			X		X	X	X	X	

Source: Energy Research and Development Administration. *The ERDA Facilities*. (Springfield, Va: NTIS, 1977.)
Each institution's current five-year plan.

PRINCIPAL SOLAR DEVELOPMENTS IN FY77

SERI and the Regional Network

In March 1977 ERDA awarded the management contract for SERI to the Midwest Research Institute. SERI began program planning in July 1977. Substantive effort in the areas of assessment and analysis, research, information dissemination, education, international programs, and commercialization soon began. Funding levels are planned to be approximately $11.8 million for FY78, $17.5 million for FY79, and $25.0 million for FY80.

To further support the solar program, ERDA authorized four regional implementation centers. The initiative to organize was left with the 50 states. All four regions have now organized; their activities are funded by six- to nine-month planning grants, varying from $0.5 to $0.8 million each.

National Center for Appropriate Technology

In April 1977 the National Center for Appropriate Technology began operations in Butte, Montana. Since then, it has funded about 70 projects, the majority of which are community demonstrations of solar energy.

HUD/DOE Solar Hot Water Initiative

HUD and DOE initiated all three phases of their solar hot water initiative in 1977. The purpose of the initiative, which is distinct from the solar demonstration cycles, is to prove the economics of solar hot water systems in three markets—single family residential, hotels/motels, hospitals and health care facilities. For the residential applications HUD distributed $4.4 million to 10 Northeastern states and Florida on the basis of population. Through various mechanisms, such as lotteries and competitive applications, the states are selecting nearly 11,000 homeowners and developers to receive $400 grants for solar hot water systems.[12]

The second phase, solar hot water systems for hotels and motels, covers 51 projects in 28 states. Administered by DOE, each grant covers from 44% to 50% of the total cost and is paid directly to the grantee.[13] The total grant amount is $3.5 million. Details on the third phase (applications closed on October 15) have not yet been announced by DOE.

Solar Heating and Cooling Demonstration Program

DOE completed the second cycle of the cost-sharing commercial demonstration program in FY77 and is currently accepting applications for the third cycle. In the same period, HUD finished the third residential cycle and is accepting applications for the fourth cycle, which will differ from other cycles in requirements for warranties and special equipment testing procedures. Total grant amount, number of projects, and number of participating states for each cycle are shown in Table 4-3. A total of four commercial and five residential cycles is planned.

Table 4-3. Solar Heating and Cooling Demonstration Program

Cycle	No. Projects	No. States	Total Grant Amount ($ Millions)
		COMMERCIAL	
1	34	22	7.5 Avg. Fed. Share-78%
2	80	33	12.6 Avg. Fed. Share-67%
3	Accepting Applications		
4			
		RESIDENTIAL	
1	55	26	1.0
2	102	36	4.0
3	169	44	6.0
4	Accepting Applications		8

Source: Solar Heating and Cooling Information Center (December 1977).

OTA Report

The Office of Technology Assessment released a draft copy of *Application of Solar Technology to Today's Energy Needs* in June 1977; it has already been widely quoted. Written for Congress, the report identifies solar issues and options and provides technical and economic analysis of solar technology impacts.

Solar Working Group Report

With technical assistance from SRI International, DOE's Solar Working Group (an advisory committee) prepared a report on solar energy. Some of the recommendations in the report are:[14]

- the current solar R&D emphasis on electrification should be reexamined;
- because the Federal solar program falls among many organizational divisions, the oversight responsibility should be fixed in a coordinating office;
- biomass and basic research should receive a major increase in emphasis.

Sun Day

A coalition of public interest, labor, and business organizations, headed by Denis Hayes, author of *Rays of Hope*, has named May 3, 1978, as Sun Day. Their hope is that the day will focus interest on solar energy through fairs, seminars, and special activities, just as Earth Day did for environmental issues.

United States and Saudi Arabia Solar R&D Agreement

The United States and Saudi Arabia signed an agreement to conduct a joint $100 million, five-year solar energy R&D program. The International Programs Branch of SERI will coordinate development of the five-year plan.

Testing of Sandia's 5 MW Solar Power Plant

Testing of Sandia Laboratories' 5 MW_t solar thermal facility on May 23, demonstrated its capability to produce a beam with over twice the energy content of any existing solar furnace, to concentrate the reflected beams on a preselected target, and to precisely track the sun.[15]

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Criticism of the Federal solar program has centered largely on issues of program management and organization, the appropriate balance of effort between solar technologies, and the use of small business versus big business contractors. Though criticism has come from many sources, the principal grievances were summarized in a series of recent *Science* magazine articles, which examined new developments in solar energy research. Excerpts from *Science* are quoted in the following text. Although the criticisms are directed specifically toward ERDA, it remains to be determined whether the DOE reorganization will respond to them.

Management and Organization

> Another criticism of the solar program is that its management has been unnecessarily restrictive. During the last 2½ years, while ERDA has directed the program, it has been guided by a management philosophy of 'aggressive sequential' development. In practice, this has meant a policy of giving priority to one solar technology in each subprogram, such as the power tower in the solar thermal program, and pushing it to quickly develop hardware and test its feasibility. What the policy has ruled out—reportedly because of skepticism from the agency leadership and budget cutting by the Office of Management and Budget—is the parallel development of competing concepts. It is, of course, possible that the best candidates were not chosen initially, but nevertheless a whole solar program could be phased out because of poor performance by an ill-advised solar concept.[16]
>
> Another problem with the solar program has been lack of flexibility, leading to too little integration of different solar technologies with each other and with the energy needs they might ultimately satisfy. This problem could be improved by focusing to a greater extent on both end-use needs and solar technologies. For example, the potential for solar solutions for the transportation sector is only indirectly addressed through electricity for electric vehicles and biomass-generated liquid fuels. Not addressed are possibilities for high-temperature thermal batteries and solar synthetic fuel production.[17]
>
> In addition, a generally acknowledged problem with the ERDA program is that its sharply divided subprogram structure has limited the development of systems that serve two purposes at once, such as total energy systems that produce both heat and electricity with a considerable improvement over the efficiency of a single purpose system.[18]
>
> The organizational structure of the energy agency, moreover, appears to be at cross-purposes with many novel or non-centralized applications. The solar energy division, for example, is effectively prohibited from working on community scale solar systems because the agency management has decreed community-oriented projects to be in the domain of the conservation directorate.[19]

The creation of the Department of Energy (October, 1977) may change the situation existing with ERDA, although the separation of the solar programs into two divisions (Conservation and Solar Applications and Energy Technology) may also create new problems. These problems will be discussed thoroughly in later *Annual Reviews*.

The Appropriate Balance Between Solar Technologies

> At the present time, the project to develop the 'power tower' is consuming 50 to 60% of the research money devoted to the conversion of sunlight into thermal energy and hence electricity. . . . Although there is some criticism that the solar program gives too little support to alternative centralized generating concepts, the research area that appears to be hardest hit by the power tower's generous funding is the development of intermediate-temperature solar thermal systems that would most likely be used on a smaller scale.[20]
>
> Recent changes have upgraded research on solar-electric systems for nonutility applications, but the bulk of solar electric research is devoted to technologies designed exclusively for large electric utilities. In the solar thermal subprogram, ERDA spent $60 million on central systems in FY77 (almost all of it for the power tower), while allocating $9 million to total energy systems.[21]
>
> Despite the diffuse nature of the [solar] resource the [federal] research program has emphasized large central stations to produce solar electricity in some distant future and has largely ignored small solar devices for

producing on-site power—an approach one critic describes as 'creating solar technologies in the image of nuclear power'.[22]

But the ERDA solar program is organized by electricity production classification rather than solar capabilities, so the various mid-temperature applications are separated from each other in a way that gives them very little visibility.[23]

Except for analytical studies, however, the federal energy research program has largely downplayed the biomass option.[24]

Big Business vs. Small Business Government Contractors

Whereas the government's nuclear program nurtured four large heavy-equipment companies that are now the sole suppliers of nuclear reactors in the United States, the power tower program is dispensing the bulk of its work to four large aerospace contractors.[25]

While the small scale wind industry has been wholly based on private funding until now, the large scale wind program has been pursued as a big-contract government R&D program with a heavy aerospace cast.[26]

In the photovoltaics area, similarly small businesses have historically played a predominant role in supplying solar cells for space and terrestrial applications. Sales to the Department of Energy during 1977 continued that status, although research contracts were more heavily granted to large businesses.

Yet the shape and scope of the [OTEC] program have been determined less by solar energy administrators than by the two large aerospace companies eager to develop the concept (Lockheed and TRW), according to many observers.[27]

Notes

[1] 42 U.S.C. 301
15 U.S.C. 764
42 U.S.C. 5903

[2] Don Miller, presentation to the ERDA General Advisory Committee, SERI, Golden, Colo., August 23, 1977.

[3] Department of Energy, "U.S. Department of Energy FY79 Budget to Congress," unpublished memo, no date.

[4] Ibid.

[5] Department of Housing and Urban Development, "Residential Energy from the Sun," booklet, December 1976.

[6] 7 U.S.C. 1281.

[7] 22 U.S.C. 2151.

[8] Murrey Goldberg, "Minutes of 38th Meeting of IPTASE," unpublished memo, September 1977.

[9] Office of the Federal Register, National Archives and Records Service, General Services Administration, *1977/78 U.S. Government Manual* (Washington, D.C.: Government Printing Office, 1977), pp. 104-105.

[10] Ibid., p. 103.

[11] Ibid., p. 99.

[12] "Hot-Water Demos—Organized Confusion," *Solar Outlook*, July 18, 1977.

[13] "Hot-Water Initiative—Better Luck This Time?" *Solar Outlook*, October 24, 1977, p. 4.

[14] Stanford Research Institute, *A Comparative Evaluation of Solar Alternatives: Implications for Federal R&D*, SRI Report, 1978.

[15] Sandia Laboratories, *STFF Reflections*, June 1977, p. 8.

[16] Allen L. Hammond and William D. Metz, "Solar Energy Research: Making Solar After the Nuclear Model?" *Science*, July 15, 1977, p. 243.

[17] Ibid.

[18] Ibid.

[19] Ibid.

[20] William D. Metz, "Solar Thermal Electricity: Power Tower Dominates Research," *Science*, July 22, 1977, p. 353.

[21] Ibid.

[22] Hammond and Metz (1977), p. 241.

[23] William D. Metz, "Solar Thermal Energy: Bringing the Pieces Together," *Science*, August 12, 1977, p. 650.

[24] Allen L. Hammond, "Photosynthetic Solar Energy: Rediscovering Biomass Fuels," *Science*, August 19, 1977, p. 745.

[25] Metz, "Solar Thermal Electricity: Power Tower Dominates Research," (1977), pp. 353-4.

[26] William D. Metz, "Wind Energy: Large and Small Systems Competing," *Science*, September 2, 1977, p. 972.

[27] William D. Metz, "Ocean Thermal Energy: The Biggest Gamble in Solar Power," *Science*, October 14, 1977, p. 178.

5. OTHER SOLAR ENERGY PROGRAMS

INTRODUCTION

This chapter summarizes formal and informal solar energy activities in the United States outside of the DOE solar RD&D programs described above and in Part II. Included here are international bilateral and multilateral solar programs in which the United States participates, state and local government programs, university research and educational programs, the activities of private industry, and individual and small scale activities.

INTERNATIONAL PROGRAMS

Introduction

The United States is involved with a number of other countries in the development and deployment of solar technologies. Table 5-1 lists those international organizations with which the United States is involved in solar activities. Table 5-2 lists U.S. cooperative international programs by nation.

International Agencies

The International Energy Agency (IEA) was established in 1974 with 19 member states. Among the purposes of the organization are long-term cooperative efforts in alternative energy sources. The IEA participating nations formed research and development working parties and designated lead countries for specific technologies. Cooperative projects are underway in heating, cooling, and solar thermal technologies. Table 5-3 shows the lead countries in these efforts. Five projects are delineated under the heating and cooling working group:

- development of solar heating, cooling, and hot water supply systems;
- development of components for solar heating, cooling, and hot water supply systems;
- performance testing of solar collectors;
- development of an insolation handbook and instrumentation package;
- use of existing meteorological information for solar energy applications.

All U.S. funds for these projects are spent in the United States under normal program funding and management. The cooperation with other countries involves designating specific projects whose objectives and results are significant to a given IEA project area. U.S. participants in these projects include universities, industries, DOE national laboratories, and other Federal agencies (e.g., NOAA and NBS). Project results and information are exchanged among those countries that are making a significant contribution to a particular area.

Cooperation in solar thermal technology under the IEA is mainly in a Small Power Systems Project to design, construct, and operate 500 kW_e power systems. About 10 countries are involved in preliminary stages of a project to develop an operational, central receiver system and/or a distributed receiver system near the Mediterranean Sea in southern Spain. The potential values of this project to the U.S. program include: (1) pooling of design capabilities and information; (2) using advanced thermodynamic cycles and advanced receiver heat transfer technology; (3) sharing of costs in developing and constructing relatively expensive experiments; and (4) gaining experience with a power system in a range of power (500 kW_e) not presently included in the U.S. program.

Discussions of cooperation with IEA nations in wind conversion, wave power, and biomass systems are continuing. It is likely that substantive projects in wind conversion will be developed. These cooperative efforts allow U.S. program managers to be aware of foreign technological developments.

COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY (CCMS)

This cooperative effort is based upon information exchange in selected areas of heating and cooling technology. All participants recognize the need for some uniformity in describing systems, installing instrumentation, obtaining data, and presenting performance results.

Table 5-1. SUMMARY OF U.S. INVOLVEMENT IN MULTINATIONAL SOLAR ACTIVITIES

INTERNATIONAL ORGANIZATION \ SOLAR ENERGY R&D AREA	SOLAR HEATING AND COOLING	PHOTOVOLTAICS	WIND	WAVE	SOLAR THERMAL	BIOMASS	OCEAN THERMAL	AGRICULTURE AND INDUSTRIAL PROCESS HEAT	TECHNICAL INFORMATION SERVICE EXCHANGE	SOLAR ENERGY APPLICATIONS	SOLAR COLLECTORS
INTERNATIONAL ENERGY AGENCY	X		X	X	X	X	X				
COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY	X				X				X		
INTERNATIONAL ATOMIC ENERGY AGENCY											X

A Solar Energy Pilot Study initiated in 1973 was established to: (1) develop an international data format to report results and programs in solar heating and cooling of buildings and (2) provide systems performance information through information exchange in subprograms and converences. Formats have been developed, and the performance of 27 buildings has been measured in nine countries. Also, a Mediterranean-climate applications group has been formed. Table 5-4 lists the member nations.

Bilateral Agreements

Bilateral agreements on solar energy technologies are in progress with France, the U.S.S.R., Spain, Japan, Denmark, and Saudi Arabia.

FRANCE

A cooperative project involving a unique French solar furnace facility has been completed successfully. This project involved testing a United States-designed solar energy receiver in the French 1 MW_t solar furnace facility in Odeillo, France, in 1976. As a result, confidence in U.S. design procedures has been increased greatly, and 5 MW_t and 50 MW_t receiver programs are proceeding on schedule. Additional cooperative projects in design and testing of solar thermal systems include aircraft safety aspects of large mirror fields (so-called glare and glint problem), wind effects on receiver thermal losses, and performance of various heat transfer fluids.

U.S.S.R.

The United States-U.S.S.R. solar energy cooperative effort has been proceeding at a relatively slow pace since 1974. Team visits have been made during the past three years—two by Soviet teams and three by U.S. teams. In September 1977, a U.S. team comprised of 11 scientists visited the U.S.S.R. Joint seminars were held in each of three technical areas on heating and cooling, solar thermal, and direct conversion. Cooperation with the Soviet Union has been largely in detailed information exchange. U.S.S.R. specialists have developed a solid analytical base in selected areas of solar technology. A team from the U.S.S.R. will likely visit the United States in the fall of 1978.

SPAIN

The U.S.-Spain Treaty of Friendship, signed in 1976, provides for cooperation in solar energy technology development in Spain. A U.S. team has assisted the Spanish scientists in establishing a national program. The immediate benefit to the U.S. solar program is involvement of U.S. industry in assisting the Spanish to demonstrate various solar applications. Such efforts give U.S. industry incentives to develop an export market.

JAPAN

Cooperation with Japan has progressed by exchange visits of scientists to Government laboratory and contractor facilities. Information has been exchanged on solar collectors, performance of photovoltaic devices, and life-testing of component materials, e.g., reflecting materials and selective coatings.

Table 5-2. SUMMARY SOLAR ENERGY PROGRAM AREA/U.S.-FOREIGN COUNTRY INVOLVEMENT

SOLAR PROGRAM AREA \ INVOLVED COUNTRY	JAPAN	AUSTRIA	BELGIUM	DENMARK	FR GERMANY	IRELAND	NETHERLANDS	SPAIN	SWEDEN	SWITZERLAND	U.K.	AUSTRALIA	CANADA	GREECE	JAMAICA	PORTUGAL	TURKEY	ISRAEL	LUXEMBOURG	SAUDI ARABIA	BRAZIL	FRANCE	ITALY	NEW ZEALAND	USSR	POLAND	EGYPT	MEXICO	ROMANIA	VENZUELA
SOLAR HEATING AND COOLING	X	X	XO	XO	XO	X	XO	X	XO	X	XO	O	O	O	O	O	O	O	O	O	O	O	O		B					
SOLAR ENERGY APPLICATIONS	B																											I		
PHOTOVOLTAICS								IB														B			B	I				I
SOLAR THERMAL		X	X		X			X	X	X								I				B	XI		B		I		I	
WIND	X		X	XB	X	X	X		X		X		X										X	X						
WAVE	X		X	X		X	X		X		X		X										X							
OCEAN THERMAL	X		X		X				X		X		X																	
BIOMASS	X		X		X	X			X	X	X		X																	
INFORMATION EXCHANGE																											I			

KEY:

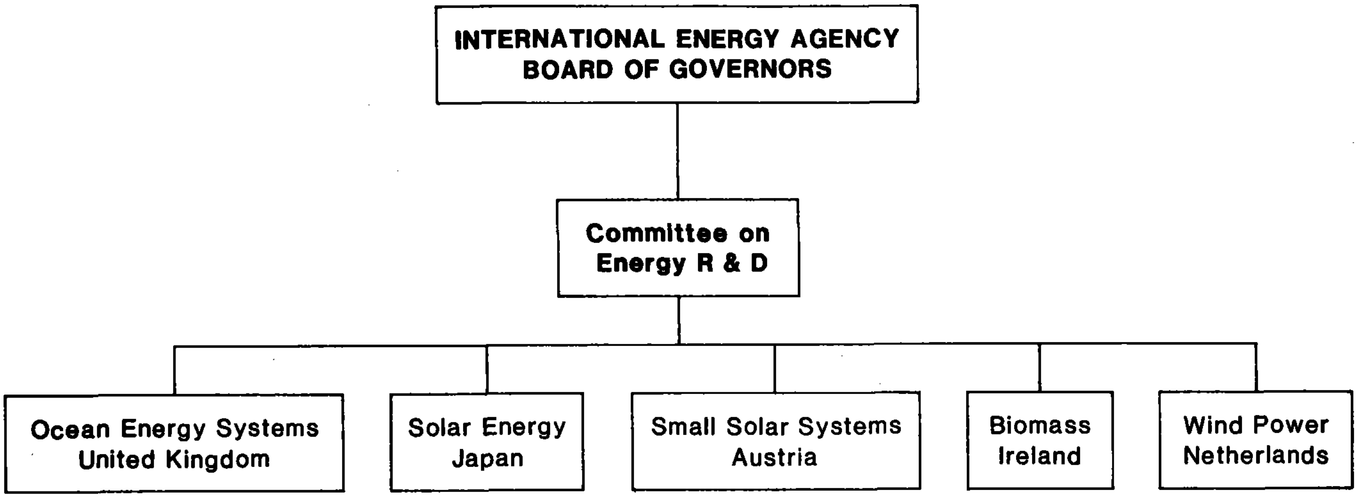
X Cooperative IEA (Multinational)

O Cooperative CCMS (Multinational)

B Bilateral U.S. Agreements

I Other Organizations

Table 5-3. INTERNATIONAL ENERGY AGENCY SOLAR RESEARCH & DEVELOPMENT WORKING PARTIES LEAD COUNTRIES



Source: R. Bracken, SERI-18, February 1978, p. 8.

Table 5-4. CCMS—Solar Energy Pilot Study Activity

Australia	Belgium	Brazil
Canada	Germany	France
Greece	Israel	Italy
Jamaica	Denmark	Netherlands
Portugal	Sweden	Saudi Arabia
Turkey	U.K.	Luxembourg
U.S. (Pilot Country)		

DENMARK

DOE has a cooperative agreement with the Research Association of Danish Electricity Supply Enterprises (DEFU) to refurbish and test the only survivor of the "older generation" of large experimental wind turbines. The "Gedsermill" has withstood 20 years of exposure to the elements (including 10 years of operation and 10 years in a nonoperational status without maintenance), and therefore it provides U.S. and Danish researchers with a unique opportunity for study of component lifetimes. The Gedser is the only survivor of a number of large experimental wind turbines tested in Europe during the 1940s and 1950s.

This entire project is expected to cost about $300,000, of which DOE has contributed about $146,000. DEFU is supplying the wind turbine and the balance of funds. The test results are being used as a basis for designing larger and more advanced American prototype wind machines. The Gedsermill resumed operating in November 1977, and tests will continue for about a year.

SAUDI ARABIA

The Department of Energy, the Department of Treasury, and the Kingdom of Saudi Arabia have undertaken a $100 million, joint, five-year, solar energy program. SERI has been assigned the responsibility for the development of a program management plan. This solar energy R&D program, based in Saudi Arabia, will concentrate on mutually beneficial technologies.

OTHER ACTIVITIES

Institutional collaborative programs involve primarily universities and are supported by and through Federal agencies with some Federal funding. These activities are primarily basic research projects covering photovoltaics, solar heating and cooling, solar thermal, solar collectors, and concentrating collectors. Some education projects also are included. Sponsoring and/or supporting organizations are the U.S. National Science Foundation (NSF), DOE, U.S.-Israel Bi-National Science Foundation (Bi-N), and the International Atomic Energy Agency in Vienna (IAEA). Table 5-5 provides a summary of program involvement by universities and other organizations in international activities. The activities at these agencies are outlined below.

NSF

Photovoltaics

- A cooperative project on the direct conversion of solar energy into electrical energy, involving three Spanish universities and several American universities, includes four work areas. The first three involve study of three types of thin-film solar cells: silicon, cadmium sulfide and gallium arsenide, and cadmium telluride. The fourth area is a general investigation of solar cell performance and energy storage problems.

- Boston College, School of Arts and Sciences, in cooperation with Spanish universities, is working on direct conversion of solar energy.

- The Institute of Nuclear Research, Swierk, Poland, is investigating the properties of Frenkel defects in single crystal semiconductors like zinc cadmium sulfide compounds.

Table 5-5. SUMMARY OF PROGRAM INVOLVEMENT BY UNIVERSITIES AND OTHER ORGANIZATIONS IN INTERNATIONAL ACTIVITIES

SOLAR ACTIVITY / COUNTRY OR ORGANIZATION	SOLAR THERMAL	PHOTOVOLTAICS	SOLAR COLLECTORS	SOLAR HEATING AND COOLING	EDUCATION	CONCENTRATING COLLECTORS
SPAIN		NSF	NSF			
POLAND		NSF				
EGYPT	NSF				NSF	
FRANCE	NSF					
ROMANIA	DOE					
ISRAEL						Bi-N
MEXICO				IAEA		
ITALY	DOE					
VENEZUELA		NSF				
INTERNATIONAL ENERGY AGENCY			DOC			

NSF — National Science Foundation
DOE — Department of Energy
DOC — Department of Commerce
IAEA — International Atomic Energy Agency
Bi-N — U.S.-Israel Bi-National Science Foundation
Source: R. Bracken, SERI-18, February 1978, p. 33.

- Pennsylvania State University, School of Science, in cooperation with the Institute Dezolano de Investigaciones-Scientificas, Caracas, Venezuela, is doing research on the properties of the generalized Schottky barrier.

- Boston College, School of Arts and Sciences, in cooperation with the Universidad Politecnia de Madrid, the Universidad Antonoma de Madrid, and the Universidad Complutense, is performing research on photovoltaics. Combination photovoltaic/solar-heating applications also will be investigated.

Solar Thermal

- New Mexico State University, School of Engineering, is performing solar thermal energy research in Egypt. This work covers a broad range of conventional and advanced solar thermal-electric conversion systems. Conventional thermomechanical systems will be examined to include: different fluids such as ammonia, propane, and freon; simple flat-plate collectors; and binary cycle systems. Application of advanced direct energy conversion systems will include: thermo-electric systems; adaptation of a solar furnace; water storage in reservoirs and tanks; dissociation of water into hydrogen and oxygen; and other methods.

- University of Arizona, in cooperation with the Centre d'Etudes Nucleaires, Grenoble, France, is studying vapor phase deposition of single-layer, spectrally selective coatings for high-temperature, photothermal, solar energy conversion. The combined effort will lead to an evaluation of refractory materials for high-temperature selective coatings used in photo-thermal conversion of solar radiation.

Education

- University of Miami, School of Engineering and Environmental Design, will present a short course on solar energy in Egypt in June 1978. This is part of a collaborative effort with the Egyptian National Research Center to investigate fundamentals, and present any future applications, of solar energy. Participant discussions will cover economic and environmental ramifications of this international effort.

DOE

Solar Thermal

- University of California, Berkeley, with project support by Icemenerg, Romania, is studying low-cost solar thermal-electric power generation. A minimum-cost, 300 MW solar electricity plant was designed, using only plentiful materials and conventional fabrication techniques. An array of steerable mirrors focuses sunshine into a long, insulated receptor, through a liquid-cooled window. Secondary mirrors inside the receptor concentrate the energy on a small blackened pipe. Most infrared reradiation and conduction losses are captured and used for feedwater preheat. Heat exchangers are located adjacent to the steam turbine. Thermodynamic optimization yielded high efficiency and very low cost.

- Georgia Institute of Technology, in cooperation with the University of Genoa, Italy, is developing and evaluating a 400 kW_t solar steam-generating plant and test facility, for installation at Georgia Tech. The program will encourage rapid transfer of state-of-the-art, Italian solar steamgeneration technology to the solar thermal conversion effort currently underway in the United States.

Solar Heating and Cooling

- The United States Department of Commerce, National Bureau of Standards, in cooperation with DOE, is establishing international standards for the design, testing, and reporting of results for solar energy heating and cooling applications within the activities of the International Energy Agency, Subproject Group on Energy R&D, Working Party on Solar Energy. Objectives of the project are to: (1) reduce costs and accelerate implementation of large scale solar heating and cooling applications by the exchange of technical information and (2) conduct joint experiments and adopt international standard methods. NBS will exchange technical information and report activities in the following areas: (1) calculation of hourly heating loads for two climatic regions; (2) preparation of a format for the reporting of solar system thermal performance; and (3) preparation of a summary of U.S. collector thermal performance and durability/reliability test results.

U.S.-ISRAEL BI-NATIONAL SCIENCE FOUNDATION (Bi-N)

Concentrating Collectors

- Two types of concentrating solar collectors designed to obtain high temperatures are being built and studied by the Israel Institute of Technology, Haifa, Israel. The first is a parabolic concentrator, having a reflector which focuses solar radiation onto a linear absorber, oriented in the eastwest direction. Attempts are being made to improve the design and technique of construction. The second collector consists of a stationary spherical reflector and a solartracking cylindrical absorber. This collector would be capable of heating, cooling, and providing hot service water for a residential building, by heating a working fluid to a sufficiently high temperature to store heat compactly and economically. An economic analysis of this system indicates that it can provide energy at less cost than can a flat-plate solar collector. The system can be mass produced, integrated into a building, and incorporated into existing heat systems.

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

- The National Institute of Nuclear Energy, Mexico City, supported by the IAEA, Vienna, Austria, is studying the use of low-cost heat sources to improve the efficiency of heap leaching of uranium ores. Heap leaching offers important economic advantages over the conventional leaching processes, where finely ground ore is treated in agitated vessels. A study will be made of design, construction, and operation of simple solar heaters for use in conjunction with heap leaching. Several solar collectors have been constructed using inexpensive and readily available materials, including flat glass panes, flat mirrors, and glass or metal tubing.

STATE AND LOCAL PROGRAMS

State Governments

The explosion of interest in solar energy across the nation has resulted in significant activities in state and local governments. Individual states have an important function in solar development because flexible policy strategies are needed to deal with regional differences in climate, energy base, political structures, and end-use energy requirements. The Federal Government necessarily assumes the lead in a wide range of activities, including regulating the price and distribution of energy, leasing of Federal lands containing energy resources, encouraging development of new energy supplies, and establishing energy efficiency standards. However, state governments provide important feedback to Federal policymakers and must establish independent local policies and organizations to deal effectively with regional concerns.

State governments have responded with a wide range of programs to the need for using solar energy. The most common action taken has been passage of legislation complementing and occasionally surpassing Federal efforts. In addition, state organizations have been established to collect and disseminate solar information, effect changes in building codes, organize conferences, and design solar energy curricula. Both the number and substance of these initiatives vary from state to state, although certain general categories of responses have emerged. State government activity in solar development and commercialization is so diverse and so rapidly growing that a comprehensive inventory of such activities would be beyond the scope of this report. The examples described below merely suggest the types of solar activity many states are now engaging in.

STATE LEGISLATIVE ACTIONS

State legislative actions can be grouped into five major categories: incentives, standards, energy consumption analysis, energy disclosure, and solar rights.

Incentives

Incentives include partial or complete exemptions from increased property taxes resulting from solar construction, income tax credits or deductions, exemptions from sales and use taxes, exemptions from franchise taxes, and low-interest loans. Most of these incentive measures are for solar equipment, although similar legislation is also urged for insulation and other energy conservation devices. Examples of such legislation are abundant. Colorado allows 100% deduction of the cost of solar equipment from the state income tax, and California has enacted a 55% state income tax credit. Texas provides exemption from sales taxes on receipts from the sale, lease, and rental of solar devices. Figure 5-1 provides a listing of state solar tax incentives; the year this legislation was passed or proposed; and the formula used in calculating exemptions, deductions, and credits.

Standards

Standards legislation addresses issues in solar building design, building products, and solar equipment. Both enabling legislation to develop mandatory standards, and mandatory standards, are being enacted. Some states, including California, Texas, and Florida, are adopting performance-oriented approaches, while most use prescriptive, or component performance, criteria.

Energy Consumption Analysis

Legislation for energy consumption analysis or energy feasibility studies has been enacted in a number of states. For example, solar energy considerations are a mandated element of comprehensive planning in Oregon. In Connecticut, life-cycle-cost analysis is required before commencing any major state capital project.

Energy Use Disclosure

Utah and Oregon have enacted legislation requiring a full disclosure of data on energy consumption and cost to potential purchasers of buildings. Other states are proposing similar actions.

Solar Rights

Procedures for creating voluntary solar easements or for including solar energy considerations in zoning and land use planning have been enacted in a number of states including Colorado, Maryland, New Mexico, and Oregon. Guaranteed access to sunlight is an important issue considering the capital-intensive nature of solar installations. Figure 5-2 presents a recent survey of solar state legislation.

OTHER STATE ACTIVITIES

Many new state organizations are engaged in solar energy information acquisition and dissemination. The following is a limited sampling of such activities. Most states have solar energy associations or energy offices, and often both. For example, New York State created the State Energy Office (SEO) in 1976, with a mandate to manage funds from the Federal conservation program. Other SEO activities include analysis of Federal energy legislation and lobbying for programs of interest to the State. The Governor's Energy Council of Pennsylvania is concentrating on solar educational activities which include developing a general information packet, organizing an internal solar information library, responding to inquiries about solar energy via a toll-free phone line, and other measures aimed at disseminating solar information. The New Jersey Solar Energy Association has similar activities. In addition, it is monitoring and recording energy savings resulting from the use of solar equipment as reported by builders and homeowners.

Local Governments

The nation's cities, towns, counties, and the other small governmental units are, like the solar resource itself, distributed and close to the people they serve. Because of this decentralized character and because local governments have wide-ranging responsibilities and opportunities to plan, to implement programs, and to regulate, they represent a potentially powerful force for solar energy development.

Localities have major responsibilities in land-use planning. A number of states have passed enabling legislation providing municipal and county governments authority to employ solar criteria in comprehensive planning. For example, Arizona enacted a bill providing authority for cities, towns, and counties to regulate access to incident solar energy. The scope of this legislation is quite general. Los Alamos County in New Mexico provides, in Ordinance 173, for protection of solar access rights. The city of Cerritoz, California, recently adopted an ordinance which incorporates into the local building codes provisions for the installation of solar energy equipment.

The legislative functions of local governments are limited. Federal and state governments exercise authority which directly affects most regional and local solar activities. In addition, local governments generally lack adequate resources to fund comprehensive programs. Nevertheless, with strong public support local governments can accomplish much. For example, grass-roots efforts in Davis, California, have led to far-reaching solar plans.

In the long run, the conflicting requirements of the approximately 30,000 local Government units may complicate solar installation activities and may necessitate unifying codes and rules.

Still, local governments will have an important function in reducing consumer perception of the risk of solar technologies and in facilitating rapid commercialization.

Figure 5-1. STATE SOLAR TAX INCENTIVES

STATE	PROPERTY (Exemptions)	INCOME (Credits, Deductions)	SALES/USE (Exemptions)	FRANCHISE/PRIVILEGE (Exemptions)
ALABAMA				
ALASKA		(77E)		
ARIZONA	(74A●)	(75A●) (76A●) (77E)		(77G)
ARKANSAS		(77A)		
CALIFORNIA	(77A)	(76E) (77E-amend.)		
COLORADO	(75D)	(77A)		
CONNECTICUT	(76A) (77A)		(77A)	
DELAWARE	(*77A)	(*77F)		
FLORIDA				
GEORGIA	(76A)		(76A)	
HAWAII	(76A)	(76D)		
IDAHO		(76G)		
ILLINOIS	(75A) (77)	(*77E)		
INDIANA	(74C) (77B-amend.)			
IOWA	(*77A)		(*77A)	
KANSAS	(77G)	(76E) (77A●)		
KENTUCKY				
LOUISIANA				
MAINE	(77A)		(77A)	
MARYLAND	(75A) (76)			
MASSACHUSETTS	(75A)	(76A) (*77F)		
MICHIGAN	(76A)		(76A)	(76A)
MINNESOTA	(*77A)		(*77A)	
MISSISSIPPI				
MISSOURI				
MONTANA	(75A)	(77G) (77G)		
NEBRASKA	(*77B,C)			
NEVADA	(77C)			
NEW HAMPSHIRE	(75A) (77A-amend.)			
NEW JERSEY	(76B) (77A)		(*76A)	
NEW MEXICO		(75E) (77)		
NEW YORK	(77B)	(*77E)	(*77A)	(*77A)
NORTH CAROLINA	(77B)	(77E)		
NORTH DAKOTA	(75A)	(77D)		
OHIO	(*77A)		(*77A)	(*77A)
OKLAHOMA		(77E and A●)		
OREGON	(75A) (77B-amend.)	(77E)		
PENNSYLVANIA	(*77C,A)		(*77A)	
RHODE ISLAND	(77B)	(*77A) (*77E) (*77D)		
SOUTH CAROLINA	(*77)	(*77G) (*77A)	(*77A)	
SOUTH DAKOTA	(75C)			
TENNESSEE	(*77)		(*77A)	
TEXAS	(77A)		(75A)	(75A) (77-amend.)
UTAH	(*77)		(*77A)	
VERMONT	(76A)		(*77A)	
VIRGINIA	(77)			
WASHINGTON	(77A)		(*77A)	
WEST VIRGINIA				
WISCONSIN	(*77A)	(*77E)	(*77A)	
WYOMING				

* = Bill Proposed
without * = Bill Passed
(76) = Year bill proposed/passed
● = credit/exemption/deduction to be amortized
A = total cost/value/price of solar system or device(s)
B = difference between cost/value/price of solar and value of conventional system
C = lesser of (B) and set dollar amount
D = set % cost/value/price of solar system
E = lesser of (D) and set dollar amount
F = set dollar amount
G = other

Source: George Morgan, SERI.

Figure 5-2. 1977 SUMMARY CHART OF STATE LEGISLATION/REGULATIONS

	IN EFFECT						PROPOSED						COMMENTS
	Standards	Enabling law for standards	Incentives	Energy consumption analysis	Energy consumption disclosure	Solar rights	Standards	Enabling bill for standards	Incentives	Energy consumption analysis	Energy consumption disclosure	Solar rights	
ALABAMA									●				
ALASKA			●						●	●			
ARIZONA		●	●									●	Solar Energy Research Comm. est. 1977
ARKANSAS			●										
CALIFORNIA	●	●	●				●		●				
COLORADO	●		●			●		●					
CONNECTICUT	●	●	●						●	●			Life cycle costing on state projects
DELAWARE							●						
DIST. OF COLUMBIA													
FLORIDA	●	●	●	●			●	●		●			Life cycle costing req'd.
GEORGIA		●	●							●			
GUAM													
HAWAII			●										
IDAHO			●										
ILLINOIS	●		●					●		●			
INDIANA		●	●										
IOWA		●							●				
KANSAS			●			●							State commission for utility connections
KENTUCKY													
LOUISIANA													
MAINE	●		●					●			●		Stds. apply to state projects
MARYLAND		●	●	●		●	●		●	●	●		
MASSACHUSETTS			●	●			●	●	●	●		●	
MICHIGAN	●		●				●		●	●			
MINNESOTA	●								●				
MISSISSIPPI													
MISSOURI								●					
MONTANA	●	●	●										
NEBRASKA													
NEVADA	●		●						●	●			
NEW HAMPSHIRE			●				●						
NEW JERSEY			●				●	●	●				
NEW MEXICO	●	●	●	●		●			●				
NEW YORK			●				●		●	●	●	●	
NORTH CAROLINA	●		●	●			●		●				Life cycle costing req'd.
NORTH DAKOTA	●		●			●							
OHIO		●					●	●	●			●	
OKLAHOMA			●					●					
OREGON	●	●	●	●	●	●							
PENNSYLVANIA							●	●	●	●			
PUERTO RICO													
RHODE ISLAND	●	●	●	●					●			●	
SOUTH CAROLINA										●			
SOUTH DAKOTA			●										
TENNESSEE										●			
TEXAS		●	●		●								
UTAH		●							●				
VERMONT			●					●	●				
VIRGIN ISLANDS													
VIRGINIA		●	●										Solar Center established in 1975
WASHINGTON	●		●	●				●				●	Life cycle costing req'd.
WEST VIRGINIA								●					
WISCONSIN	●						●						
WYOMING													

Source: G. Morgan, SERI.

UNIVERSITY AND COLLEGE SOLAR ENERGY PROGRAMS

Introduction

Universities and colleges have had a vital role in providing manpower training and in fostering innovative ideas. This community provides four essential ingredients to the Federal program. First, universities and colleges are a source of a broad range of professional talents. Second, these institutions train the manpower required in the solar energy field. Third, the research facilities and staffs are an online responsive resource. Fourth, academia provides a broad range of supportive functions for the community at large in organizing conferences, in offering continuing education courses, and in providing technical and professional journals and publications.

Funding

The Department of Energy (and previous Federal agencies) in recent years has increasingly supported solar research, development, and commercialization. A summary of university and college budget obligations is presented in Table 5-6.

Traditionally, many new ideas have been generated in academic circles. A substantial portion of RD&D funds is allocated in universities by government solicitations for research. Often this research is of a practical nature. For example, a $11,000 project at Louisiana State University to study the harvesting and transportation of sugar cane is essentially engineering work. A $137,000 Stanford University study of heat treatment of organics for increasing anaerobic biodegradability addresses more basic issues. In FY78, $4.0 million of the total $9.46 million allocated to universities for solar R&D can be considered, as an optimistic estimate, basic research. Two trends in the Federal support of academic research are demonstrated in Figure 5-3. First, the total RD&D/Support Budget as a percentage of the Federal solar program budgetary outlays has dramatically decreased. Second, support funds for conferences, legal studies, and other nonbasic research efforts have been reduced. However, these results must be viewed in comparison with other Governmental nonsolar activities before meaningful conclusions can be drawn.

Table 5-7 presents a five-year survey of solar research funding at universities and colleges in relation to nonsolar academic research. (See Figure 5-4 for a graphic summary of these data.) Next, a comparison of university RD&D as a percentage of the total RD&D budget in a number of other Government agencies is presented in

Table 5-6. UNIVERSITY & COLLEGE BUDGET OBLIGATION
(Excluding Demonstrations)
($ in thousands)

	Cumulative to FY76	FY77	FY78
Support Activities:			
Conference & Workshops	254	536	201
Bids & Construction	1,819	1,584	167
Solar Energy Data Collection & Evaluation	1,083	2,012	370
Course & Manual Preparation	0	244	0
Technology Assessment, Legal Studies, etc.	441	1,032	1,124
University Solar R&D	11,442	10,839	9,487*
Total University Solar R&D/Support Budget	15,039	16,247	11,349
Federal Solar Program Budget	182,000	290,000	411,00
Total University Solar R&D/Support as % of Federal Solar Program Budget	8.3%	5.6%	2.8%
University Solar R&D as % of Federal Solar Program Budget	6.3%	3.7%	2.3%

*The $9.487 million University R&D includes an optimistic estimate of $4.0 million for basic university research. See text for details.

Source: G. Warfield, SERI.

Table 5-7. UNIVERSITY AND COLLEGE ERDA/DOE BUDGET OBLIGATION

(Demonstrations Included)

($ in millions)

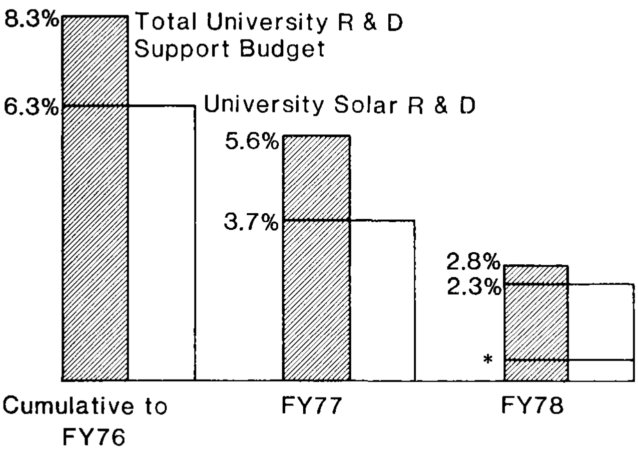
	FY75	FY76	FY77	FY78	FY79*
Total Federal RD&D Budget	2,072	2,499	3,575	4,231	4,245
University Total RD&D Budget	135.0	180.6	181.5	205.5	230.3
University Solar RD&D Budget	3.4	8.2	18.7	15.5	16.2
Total Federal Solar Program Budget	41.9	115	290	411	400
University Solar RD&D to University Total RD&D Budget	2.6%	4.6%	10.3%	7.6%	7.0%
University Solar RD&D to Federal Solar Program Budget	8.3%	7.2%	6.4%	3.8%	4.0%
University NonSolar RD&D to Total Federal NonSolar RD&D Budget	6.5%	7.2%	5.0%	5.0%	5.6%

*Official OMB Office of the Controller Estimates.

Table 5-8. These figures are derived from FY79 official OMB estimates.

The Department of Energy as a mission-oriented organization will fund a lower percentage of university research in FY79 than will a number of other Federal agencies (Table 5-8). Figure 5-4 indicates that the trend toward a rapid increase in the ratio of solar to nonsolar university research reversed in FY77. Also, though solar research at universities and colleges had been funded as well as, or better than, nonsolar university R&D (relative to total solar and nonsolar R&D budgets, respectively), this trend recently has reversed.

Figure 5-3. UNIVERSITY & COLLEGE BUDGET OBLIGATIONS AS A PERCENTAGE OF FEDERAL SOLAR PROGRAM BUDGET (Excluding Demonstrations)



*1% optimistic estimate of basic University research.

Several explanations of the apparent decreased importance of the role of academic institutions in the national solar energy program are possible. Shock of the oil embargo, coupled with perception of an imminent energy crisis, created a sense of urgency leading to an emphasis on developing, demonstrating, and commercializing alternative energy supplies as rapidly as possible. Many solar technologies had passed the research stage and were ready for rapid commercialization. In addition, decreasing enrollment in universities and colleges and increasing opportunities for professionals in the energy field may have redirected some funds from academic to industrial and Government laboratories.

Universities and colleges have a vital role in solar R&D, both in the invention and importance of solar technology and in the study of the social role and impacts of solar energy. In addition to existing programs, a number of new initiatives are being considered. First, the possibility of increasing front-end, conceptual research at universities is being considered. Second, curricula development, workshops, and coordination with the office of university programs in the Intergovernmental and Institutional Relations Branch of DOE are being planned. Third, exchange programs are being considered between universities and SERI. The program would include sabbatical residence at SERI of university faculty. These exchanges, involving American and foreign professionals, would also include visits of graduate students to complete their research programs in SERI laboratories. Finally, a university advisory panel to SERI is being organized.

Table 5-8. FEDERAL UNIVERSITY RESEARCH FUNDING (FY78)

	% University Research of Total RD&D Budget	% University Research of Basic Research Budget	%University Research of Applied Research Budget
DOE	5	21	15
DOD	3	41	6
NASA	3	19	3
NIH	52	68	55
NSF	73	75	45
Department of Agriculture	31	31	29
EPA	9		
All Agencies		46	20

INDIVIDUAL AND SMALL SCALE ACTIVITIES

Current Activities

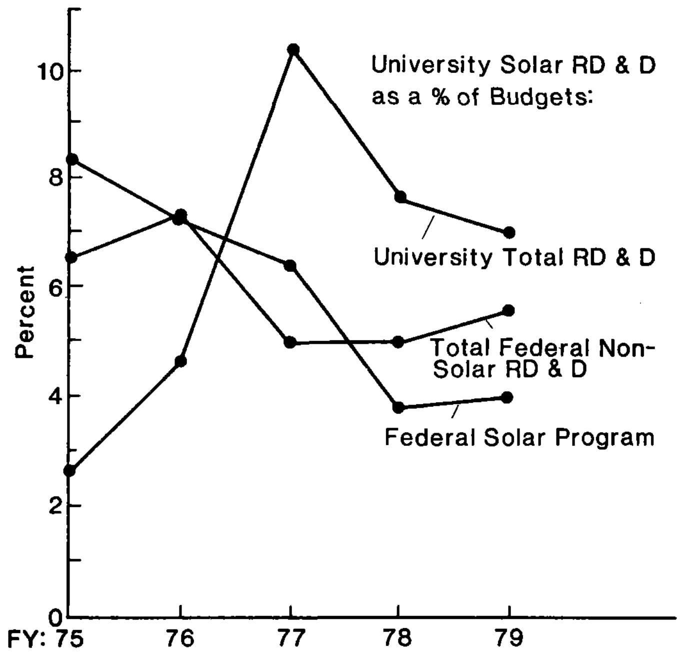
An increasing amount of the work which is taking place in solar energy is being done by individuals without Government support or funding. Many of these people are involved in self-help (self-taught) solar efforts. They are designing and constructing solar-heated homes, solar water distillation units, and solar hot water heating systems. These individuals teach themselves the simple skills necessary to solve immediate problems, e.g., saving money on utility bills. Furthermore, they view self-help efforts as a way to actively do their part as citizens in addressing our energy problems.

In addition to self-help solar activities, there are many small businesses (both product- and service-oriented) now active in the solar market. Although the majority of these small solar-related businesses have been operating outside the mainstream of Government funding, their efforts are beginning to receive attention at the national level. Several small pilot programs in the area of "appropriate technology" (which includes decentralized solar and other renewable resource and small-scale technology applications) are being supported by various Federal agencies. The Community Services Administration is involved with the National Center for Appropriate Technology; the Department of Energy has established two regional small grants programs; and the Agency for International Development has supported a new organization called Appropriate Technology International. The total yearly support for these programs is approximately $10 million.

In his National Energy Plan of April 1977, President Carter proposed a new Office of Small-Scale Technology within DOE. Senators Percy, Metzenbaum, and Humphrey reaffirmed the need for such an office in a widely circulated letter to DOE Secretary Schlesinger in late 1977. Included in this letter was the following statement:

> In order to realize . . . [small scale energy technologies'] promise for increasing our national energy supplies, government commercial policies which are critical to the success of renewable energy systems must be tailored to the particular needs

Figure 5-4. RD&D BUDGET OBLIGATIONS AT ERDA/ DOE (Including Demonstrations)



of decentralized applications, and must specifically address the difficulties of dealing with small, undercapitalized firms.

Agriculture is another area in which many individuals and small groups are working with solar energy. Experiments and demonstrations are being conducted in such activities as solar grain drying, solar crop drying, and solar heating of greenhouses. The solar collector is being experimented with for multiple on-farm uses—grain drying, hay drying and heating of farmhouses and livestock buildings.

An example is the Nebraska Low Energy Agriculture Project, sponsored by the Center for Rural Affairs. This is a research and education effort for the gathering and dissemination of material about the use of solar energy sources for on-farm applications. Another is the Northern New Mexico Solar Sustenance project which designed and built several attached solar greenhouses which simultaneously grow food and produce usable household heat.

From a study of the literature and a 1977 survey of similar self-help and small business groups, the authors of that survey estimate that there are about 5000 currently active local self-help solar groups and solar small businesses in this country.

Difficulties Faced by Local Individuals and Groups

Self-help innovators face problems because of lack of information and lack of contact with others interested in similar projects. In the responses to the survey mentioned above, the authors noted several major problems faced by this group:

- They have few opportunities to upgrade skills in a cost-effective manner.

- They lack funds for educational materials, demonstration projects, extension workers, or local educational programs.

- They need assistance from scientific institutions with the testing of prototypes (in the design of experiments, in the use of testing equipment, and in the interpretation of results).

- They lack learner-based educational opportunities to facilitate the enhancement of individual and cooperative skills which could address household and local community renewable energy needs.

Many respondents, after experience with self-help efforts, have begun to explore the small business potential of solar energy sources. However, a series of problems which generally trouble the small business community hampers these operations also:

- Federal, state, and local regulations have reached an extreme level of complexity. Inventors, small research and development groups, and small businesses face long regulatory delays at exactly the period when new ventures are hard pressed for carry-over capital.

- The small inventor/entrepreneur has difficulties with the patent system. It is perceived as confusing, expensive, and presenting a delay that often stretches over a period of years.

- Small research and development companies have trouble finding support for what they feel is valuable work unless it fits within the guidelines set for large Federal contracts with large firms. Small companies feel that this leads to simplistic, one-dimensional solutions.

Those in small solar energy businesses reported that they face a series of market problems even more severe than the capital squeeze and regulatory problems of other members of the small business community:

- These groups lack the subsidies which have been built into the tax structure for conventional energy sources. Further, initial costs for the systems are high, and consumer confusion about government policy (in regard to future price escalation for energy) slows investment in alternatives.

- Because initial investments are higher, families often cannot use the products or services these new businesses make available.

Further, only a small number of colleges and universities have been involved in renewable AT or small scale energy projects. Few extension services exist to help local individuals or groups. Lack of funds, managerial staff, and committed students are serious obstacles that limit higher education resources in this field.

Recommendations

Much can be done to stimulate the efforts and overcome the obstacles mentioned above. Several recommendations are made by the authors of the AT surveys.

- Through use of Federal Block Grant Funds, the Federal Government could:

    * furnish matching funds to innovative state programs which are geared to local experiments and/or which provide services to those involved in small enterprise developments;
    * provide matching funds to existing publishers in the field of information networks to encourage wider as well as more in-depth coverage of issues and opportunities related to appropriate technology;
    * provide grants to cover the overhead of state or regional conferences, fairs, and planning sessions which will establish or continue innovative information linkages and interchanges.

- In liaison with foreign assistance agencies, the Federal Government could:

    * evaluate present techniques and develop new techniques to further reduce costs and make appropriate technologies

accessible in a wide variety of local situations where skills and materials may be limited;

support a program of fellowships and student prizes which could foster the transmission of skills and techniques in these areas from the developed to the developing countries.

SOLAR INDUSTRY

Solar industry spans a wide range of specialized fields (Figure 5-5). The direct and indirect forms of the sun's energy have generated technologies to use that energy efficiently. The technologies include solar heating and cooling of buildings, photovoltaic cells, wind energy conversion systems, biomass, and solar thermal. Over 700 firms are now involved in the solar field, manufacturing primary and secondary solar equipment.[1] One publication has categorized solar products within the Construction Specification Index (CSI) in an effort to standardize the different solar components and systems.[2]

Solar Heating and Cooling of Buildings

Solar heating and cooling of buildings (SHACOB) has been by far the largest and most widely commercialized solar technology. The growth in collector manufacturing shown in figure 5-6 indicates the rapidly increasing public awareness of SHACOB.

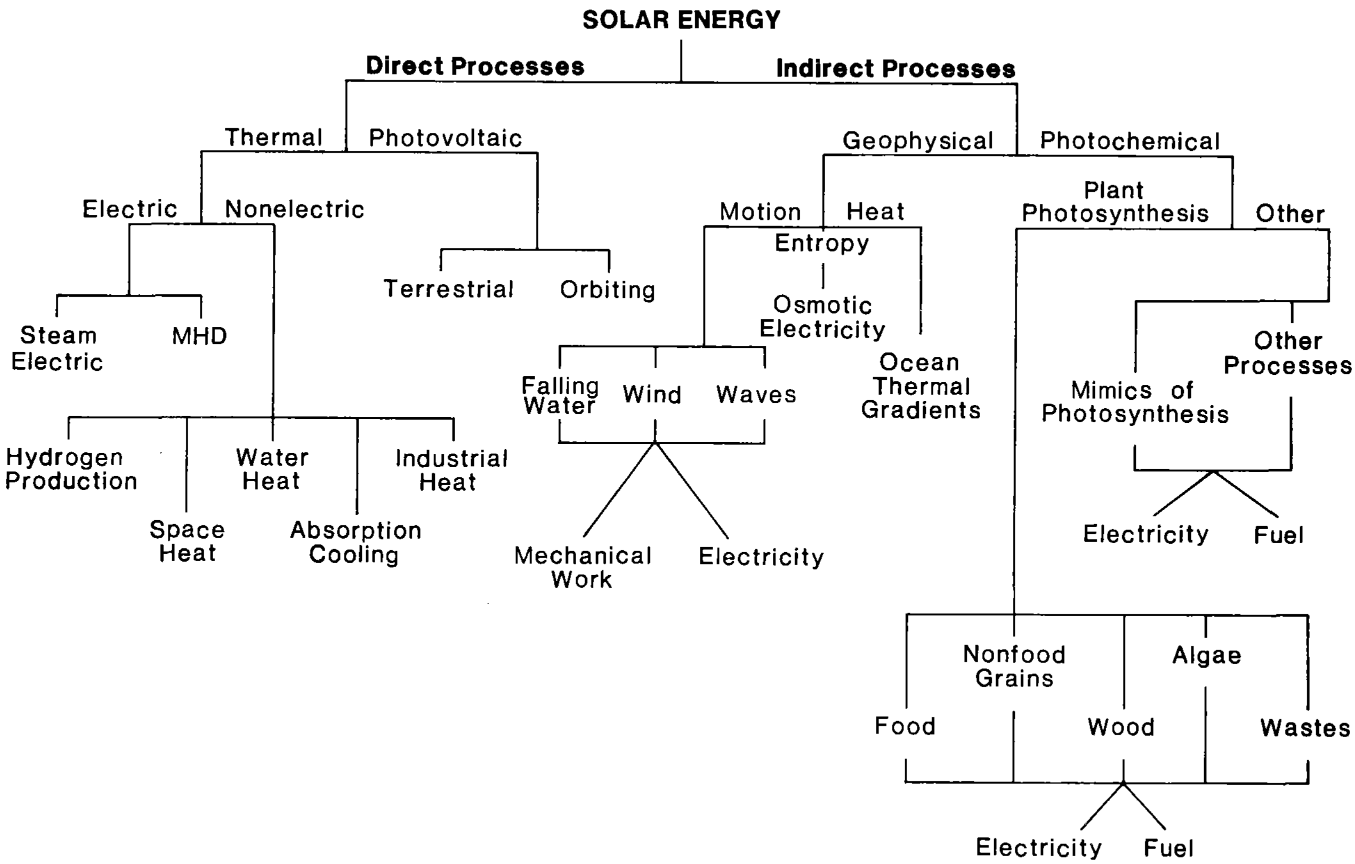
According to FEA reports on collector manufacturing activity, the number of solar manufacturing firms surveyed in 1974 was 39 for medium-temperature collectors and 6 for low-temperature ones. These figures increased to 118 and 13 in 1975 and 203 and 19 in 1976. Other sources report a large number of manufacturers for 1977.[3]

More than 60% of the SHACOB market (by dollars or square footage) is devoted to supplying hot water.[4] However, designs combining space heating and water heating as well as new architectural and construction techniques to use the sun's energy passively are being rapidly developed. Solar assisted heat pumps show a promising future; systems are now being marketed. Solar cooling, though still primarily in the research stage, may also account for a large segment of the SHACOB market in future years.

The sales of solar equipment for heating and cooling in 1973 were less than $1 million, but by 1976 the sales were between $40-50 million. The 1977 sales estimates were between $140-150 million.[5]

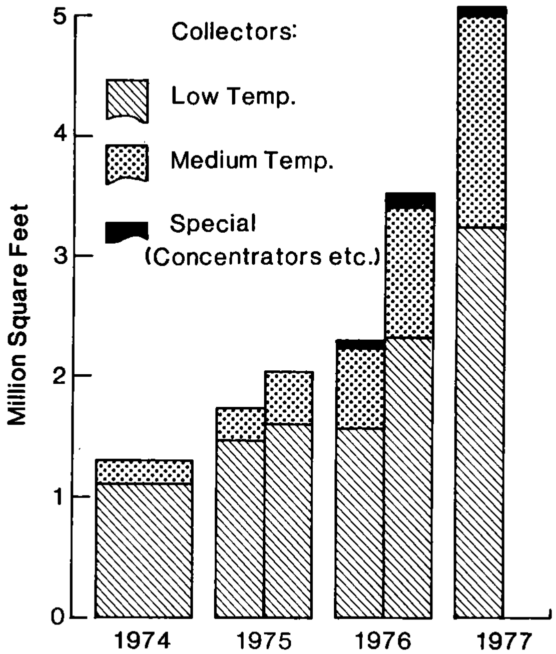
The breakdown by system types for 1977 is given in Table 5-9.

Figure 5-5. THE SOLAR INDUSTRY



Source: P. R. Ehrlich, A. H. Ehrlich, J. P. Holdren, *Ecoscience: Population, Resources, Environment*, (San Francisco: W. H. Freeman and Co., 1977).

Figure 5-6. SOLAR COLLECTOR MANUFACTURING ACTIVITY, 1974-JUNE 1977*



Source: FEA and DOE, *Solar Collector Manufacturing Activity* Reports.

*Data for July-December 1977 not available.

Estimates of the SHACOB market for 1985 are \$0.8-1.5 billion.[6] Some are more optimistic, estimating that sales could reach \$1 billion in the early 1980s and approach \$24 billion by the 1990s.[7]

Estimates for the availability of economical SHACOB systems vary from 2 to 20 years. A system is considered economical when the interest payments on the borrowed initial expenditures are less than the fuel saving from using solar. Variations in these estimates arise from different projections of fuel cost increases and solar equipment cost decreases over the next few years.[8]

Table 5-9. SALES OF SOLAR EQUIPMENT BY TYPE AND MARKET SEGMENT

Sales Volume-1977	\$145 million
	%
Systems Type:	
hot water	61
heating/hot water	38
heating/hot water/cooling	1
	100
Market Segment:	
residential	82
commercial	18
	100

Source: ***Solar Heating and Cooling of Buildings Commercialization Report, Part B.*** **A.D. Little, Inc., September 1977, p. 27.**

Domestic hot water is needed year round, making life-cycle costs of solar water heating systems very attractive, with a payback period of less than 10 years. Initial estimated costs for water heaters that provide between 40-70% of domestic hot water requirements range from \$1000 to \$1500, uninstalled.[9]

The majority of the solar industry at present is comprised of small companies, but several large corporations are preparing for large scale production.[10]

Several companies enter and leave the field every year—a trend that is likely to continue in the near future. During July-December 1976, 34% of the total number of companies were new solar energy collector producers. In that same period, 18% stopped production. This indicates that this industry is not yet a stable one, and only the large producers are retaining a relatively high degree of stability.[11]

Solar Engineering Magazine reports that the largest producer of solar air systems in the United States has an output of 2400 sq. ft. of collector per day. The manufacturing is contracted at four U.S. locations and the systems are sold in a complete package that includes all the hardware needed for installation.[12] Its sales breakdown is approximately 60% residential, 25% commercial, 5% industrial, and 10% agricultural.[13] Its marketing approach includes the complete integration of the systems, training programs, development of engineering expertise, and vertical quality control from the manufacturing to the final installation and distribution through HVAC dealers.[14]

Many companies rely on a network of distributors and/or dealers for the commercialization of their products. It has been reported that one company has established 35 distributors and 250 dealers for their liquid systems. Its production approaches (Dec. 77) 1500 units per month.[15] System installers are in many instances trained by the factories in order to assure a uniform installation procedure.

A conflicting trend in the industry is the emergence of "solar packagers." Solar packagers resell the system to installers or anyone else. They are the link between the manufacturer and the consumer and are a time saver for the contractor. One expert predicts that the packagers will disappear as soon as the industry consolidates, and people are able to put the systems together themselves.[16] Another expert contends, however, that the packagers will remain as a major component of the industry as a result of the strong position they are currently acquiring.[17]

Some companies have capitalized on the expertise that solar firms in foreign countries have acquired. They have set up distributorships and manufacturing plants based on the original system specifications. In some cases companies have merged in order to capture a larger share of the U.S. market and to produce a competitive product on an international basis.[18]

Solar advertising is needed to enter the market and also to educate the general public. One large company launched a major advertising campaign in late 1976 featuring its line of products and a general outline of the solar process. The response was reported to be 60,000 inquiries and many orders throughout 1977. Creation of public awareness is also related to the increased sales and credibility of the entire industry.[19] Another tactic aimed at enhancing consumer confidence is the provision of a solid warranty. One company provides a five-year warranty on collectors, heat exchangers, hot water storage tanks, controls, and interconnecting pipes.[20]

Wind Energy Conversion Systems

Wind energy conversion system (WECS) manufacturing firms have existed in the United States for a relatively long time. The second half of the 1800s and the early 1900s saw an estimated six million small (under 1 hp or 0.75 kW) wind machines built and used. Some 150,000 are still in use, mostly for water pumping.[21] The industry virtually disappeared until the 1970s when renewed public interest in wind power encouraged research, development, and production, resulting in a new period of growth.

The new WECS are used primarily for pumping water and generating electricity. Other uses, such as heat generation, are being studied on a very small scale. According to one report, manufacture and sales of wind machines for water pumping during the years 1975 and 1976 were stable at 2500 units per year.[22] Another source estimates that 25,000 (up to 2 kW or 2.6 hp) water pumping units were sold in 1976, a large number of which were exported.[23] The capital cost (1977) of small water pumping units in 1977 dollars were reported to be between $1300/kW and $1500/kW.[24]

It has been reported that the manufacture and sales of electric wind generators increased over 50% in 1976 from a base of 750 in 1975. These figures include imports, which have been comprising a high percentage of sales, especially in the larger (2-10 kW) electric generators. Smaller electric generating systems, up to 2 kW, are being produced in the United States, and research and development of the larger machines (2-10 kW) are in progress.[25] Another report estimates that production of machines around 5 kW in 1976 was between 100 and 500 units.[26] Two companies have their WTG machines on the market for about $1533/kW and $2000/kW respectively.[27]

One source reports 23 manufacturers and distributors for 1976, of which 11 manufacture and distribute, 7 distribute, 1 produces prototypes, and 4 are system designers.[28] Another source reports 21 manufacturers of wind turbine generators alone.[29] Still another publication lists 22 companies as of Fall 1977. Four of these companies were foreign, and five of the United States companies manufacture water pumpers.[30]

A very rough estimate of the WECS production breakdown is:

40% foreign manufacture
40% U.S. (includes rebuilt machines)
20% miscellaneous (prototypes, home production, etc.)[31]

Reports on manufacturing activity and number of manufacturers are conflicting and, in many cases, incomplete. The amount of production varies from report to report, and information is not always readily available from the proper sources. However, rapid growth of the industry does seem to be one trend that is generally accepted.[32]

Photovoltaic Cells

The photovoltaic manufacturers seem to be optimistic about their growth in 1978. Sales to the Government are primarily responsible for their growth, but private market sales are expanding rapidly.[33]

There is no consensus about the size of the industry, since manufacturers are reluctant to release data on their production. Estimates for 1977 range from 1 MW (space and terrestrial) down to 400 to 600 kW (U.S. production) and 750 kW (worldwide). A more conservative estimate of 400 to 600 kW (worldwide) production has also been reported. Production of solar cells is conservatively expected to double in 1978. Other estimates predict volumes as high as 1.3 to 1.5 MW for 1978.[34]

"In 1975 the Jet Propulsion Laboratory (JPL) purchased cells at $30 per peak watt with an array efficiency of 6 to 7%." During 1977 (up to November) they bought cells for as low as $13 per peak watt with a 7% array efficiency. As production doubles, many expect price reductions to continue in the range of 20% to 30% each year.[35] One trade directory reports 22 manufacturers, including some firms which have not yet started marketing their products.[36] In a survey of 14 photovoltaic firms, it was reported that 11 of them employed over 1300 people and the average array price was $19.80/kW.[37] Four producers are reported to lead the photovoltaic industry, largely as a result of their Government contracts. These four firms supplied 135 kW to the Government in 1977, mostly through purchases by JPL.[38] One firm has teamed up with a foreign company to manufacture cells abroad[39] and has expanded their marketing efforts to include several countries.[40]

Notes

[1]"Developing an Index System for Solar Systems and Components," *Solar Engineering Magazine*, December 1977, p. 33.

[2]Ibid.

[3]Ibid.

[4]*Solar Heating and Cooling of Buildings Commercialization Report, Vol. II, Part B*, A.D. Little, Inc., September 1977, p. 27.

[5]Ibid.

[6]Ibid.

[7]Solar Energy Industries Association, 1976 estimate.

[8]*Solar Technology*, June 1976, pp. 11-12.

[9]A.D. Little estimates or cited by *Chemical Market Review*, January 3, 1977, pp. 4; 68.

[10]*Solar Heating and Cooling of Buildings, Commercialization Report, Vol. I, Part B*, A.D. Little, Inc., September 1977, pp. 16-17.

[11]*Solar Collector Manufacturing Activity*, July through December 1976, Federal Energy Administration, April 1977, p. 6.

[12]"Solaron Holds Its Own—First with Air Systems," *Solar Engineering Magazine*, December 1977, p. 12.

[13]Personal Communication, J. Junk, Solaron Corporation, to E. Groyret, Solar Energy Research Institute, January 12, 1978.

[14]"Solaron . . . Air Systems," *Solar Engineering Magazine*, December 1977, p. 12.

[15]"Strong Distribution Network Carries the Word for Revere," *Solar Engineering Magazine*, December 1977, p. 18.

[16]"Lennox-Honeywell Team Skills Show on Successful Bidding," *Solar Engineering Magazine*, December 1977, pp. 16-17.

[17]Ibid., p. 28.

[18]*Solar Energy Intelligence Report*, January 16, 1978, p. 18.

[19]"Grumman Solar Ad Campaign Captures Consumer Attention," *Solar Engineering Magazine*, December 1977, p. 14.

[20]*Solar Outlook*, January 23, 1978, p. 6.

[21]The MITRE Corporation, "Preliminary Wind Energy Commercialization Program," November 1976.

[22]Federal Energy Administration, *WECS Manufacturing and Sales Activity, 75-76*, FEA/B-77/121 (April 1977).

[23]SERI Internal Memo, November 4, 1977.

[24]SERI Internal Memo, November 4, 1977.

[25]FEA, *WECS* (1977).

[26]SERI Internal Memo, November 9, 1977.

[27]Based on distributors' quote for a remanufactured Jacobs Machine and a Dunlite machine.

[28]FEA, *WECS* (1977).

[29]Rockwell International, "Wind Energy Information Letter," Rocky Flats, Colorado, December 1978.

[30]*Wind Power Digest*, Fall 1977.

[31]Terry J. Healy, Rocky Flats, Rockwell International, at SERI meeting, January 10, 1978.

[32]SERI Internal Memo, November 4, 1977.

[33]*Solar Engineering Magazine*, November 1977, p. 12.

[34]Ibid.

[35]Ibid., p. 15.

[36]Ibid., p. 35.

[37]Ibid., p. 14.

[38]Ibid., p. 15.

[39]*Solar Outlook*, January 30, 1978, p. 1.

[40]*Solar Engineering Magazine*, November 1977, p. 15.

6. MAJOR FORCES AFFECTING THE FUTURE OF SOLAR ENERGY

The exact path of the development of solar technology in the United States cannot be predicted. Recent studies do identify, though, the trends and events which are likely to have a major influence on the role of solar energy in America's future. They include aspects which are economic, social, environmental, and have to do with R&D and Government policy.

ECONOMICS

The Price and Availability of Oil and Natural Gas

The SRI study, "Solar Energy in America's Future," found that the future prices of the current major energy sources—oil and natural gas—would be the most important determinant of the rate and scale of commercialization of solar energy.[1] This observation seems to be supported by virtually every major study. In general, the more rapidly the prices of these now-dominant fossil fuels increase, the greater becomes the market potential for solar technology. The Federally regulated low price of natural gas especially is seen as a barrier to the accelerated use of solar energy. However, it should be noted that price projections alone do not determine the market potential of solar technology. Availability of fuels is just as important a factor in determining the solar market potential. Prices of oil and natural gas are now determined largely by fiat of national governments and may not be an accurate indicator of the actual availability of these fuels. Where these fuels are in short supply (whether on a large scale or a local basis), solar may be an attractive energy source, regardless of its possibly higher price. For example, in many areas of the United States, lack of adequate gas supplies at the regulated price has led utilities to ration new gas taps. As a result, the majority of new homes constructed in the United States (and virtually all new homes in gas-short areas) are equipped with electric heat.

To the extent that future energy supplies may be subject to rationing of one sort or another, the prospects for the use of solar energy may be greater than what prices might predict.

The Price of Nuclear and Coal Plants

The installed price of nuclear and coal power plants has risen dramatically over the last two decades. The price of both nuclear fuel and coal has also risen at a rate greatly accelerated compared to general inflation. The extent to which these price trends continue over the rest of the century will have a significant impact on the marketplace suitability of various solar electric options.

Capital Requirements

Solar energy will probably be a highly capital-intensive form of energy and usually will be justified economically only on a life-cycle costing basis. These charateristics will have a strong impact on the consideration of solar plants during times of tight capital. Life-cycle costing is not currently a standard procedure in the energy business. The extent to which life-cycle costs are considered in making energy investments will strongly influence future solar acceptance.

Structure of the Energy Industry

Control of the U.S. energy industry is now heavily concentrated in a small number of major corporations. The structure of the energy industry has been determined partly by Government tax and regulatory policies and partly by the particular economics of energy development.[2] The way in which the present structure is maintained or transformed in the future will have a powerful influence on the scope and forh of solar development.

Business Ownership

The pattern of ownership of American enterprise is now undergoing a rapid and dramatic transformation. In the near future, a majority of U.S. capital is expected to be owned by large institutions, notably pension funds, insurance companies, and banks.[3] (See Table 6-1) Simultaneously, foreign ownership of American land and capital is growing, largely as a result of the still-increasing U.S. dependence on foreign oil.[4] (See Figure 6-1) These changing patterns of ownership will influence the development of the U.S. solar industry.

Organizational Forms

The future evolution of the solar industry will also be affected by the changing form of business organization. While some analysts foresee the growing concentration of economic control leading to

Table 6-1. CHANGING DISTRIBUTION OF U.S. STOCKHOLDINGS 1970-1977

110	January 1970	Percentage of Total	January 1977	Percentage of Total	Change in Percentage
REDUCTION IN STOCKHOLDINGS					
Individuals	$582.1 bil.	66.9%	$508.6 bil.	53.2%	−13.7%
Mutual funds, investment companies	$ 51.3 bil.	5.9%	$ 48.9 bil.	5.1%	− 0.8%
INCREASE IN STOCKHOLDINGS					
Bank trust funds	$ 84.2 bil.	9.7%	$103.2 bil.	10.8%	+ 1.1%
Private pension funds	$ 61.4 bil.	7.0%	$109.7 bil.	11.5%	+ 4.5%
Foreign investors	$ 26.9 bil.	3.1%	$ 61.4 bil.	6.4%	+ 3.3%
Foundations	$ 20.0 bil.	2.3%	$ 27.1 bil.	2.8%	+ 0.5%
Insurance companies	$ 27.0 bil.	3.1%	$ 51.6 bil.	5.4%	+ 2.3%
State, local retirement funds	$ 7.3 bil.	0.8%	$ 30.1 bil.	3.2%	+ 2.4%
College, educational endowments	$ 7.6 bil.	0.9%	$ 10.4 bil.	1.1%	+ 0.2%
Mutual savings banks	$ 2.5 bil.	0.3%	$ 4.4 bil.	0.5%	+ 0.2%
TOTAL	$870.3 bil.	100.0%	$955.4 bil.	100.0%	0

Note: Investment-company shares held by other institutional groups are counted twice, by amounts of $4 billion in 1970 and $10 billion in 1977.
Source: *U.S. News & World Report* (July 18, 1977); Securities and Exchange Commission.

"the supercorporation,"[5] others anticipate a reversal of this trend, and the eventual decline of "business civilization."[6] In any event, few expect the present structure of business organization and management to remain static.

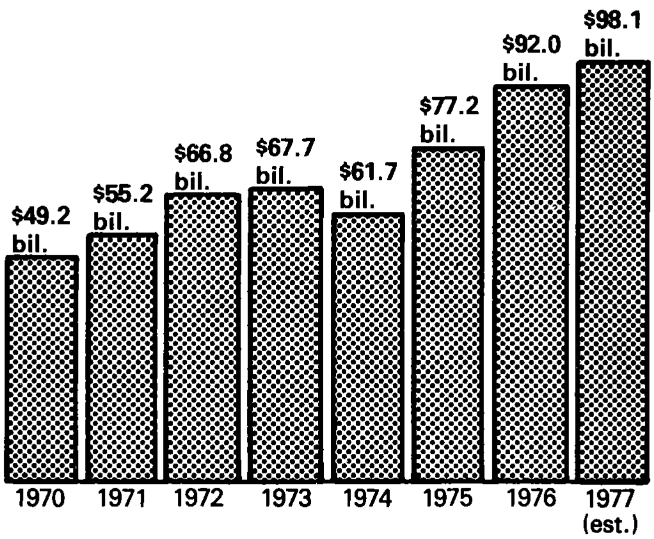
Growth

Inevitably, solar development will be affected by the growth of the U.S. economy; but how solar will be influenced by economic growth is not obvious. Solar development might be either advanced or retarded under conditions of continued exponential growth or, at the opposite extreme, of a major recession or depression. The economic valuation of solar energy also will be influenced by the future relation between energy consumption and Gross National Product,[7] and indeed, by whether GNP continues to define an economic goal or is replaced by some other measure of national economic welfare.

Labor

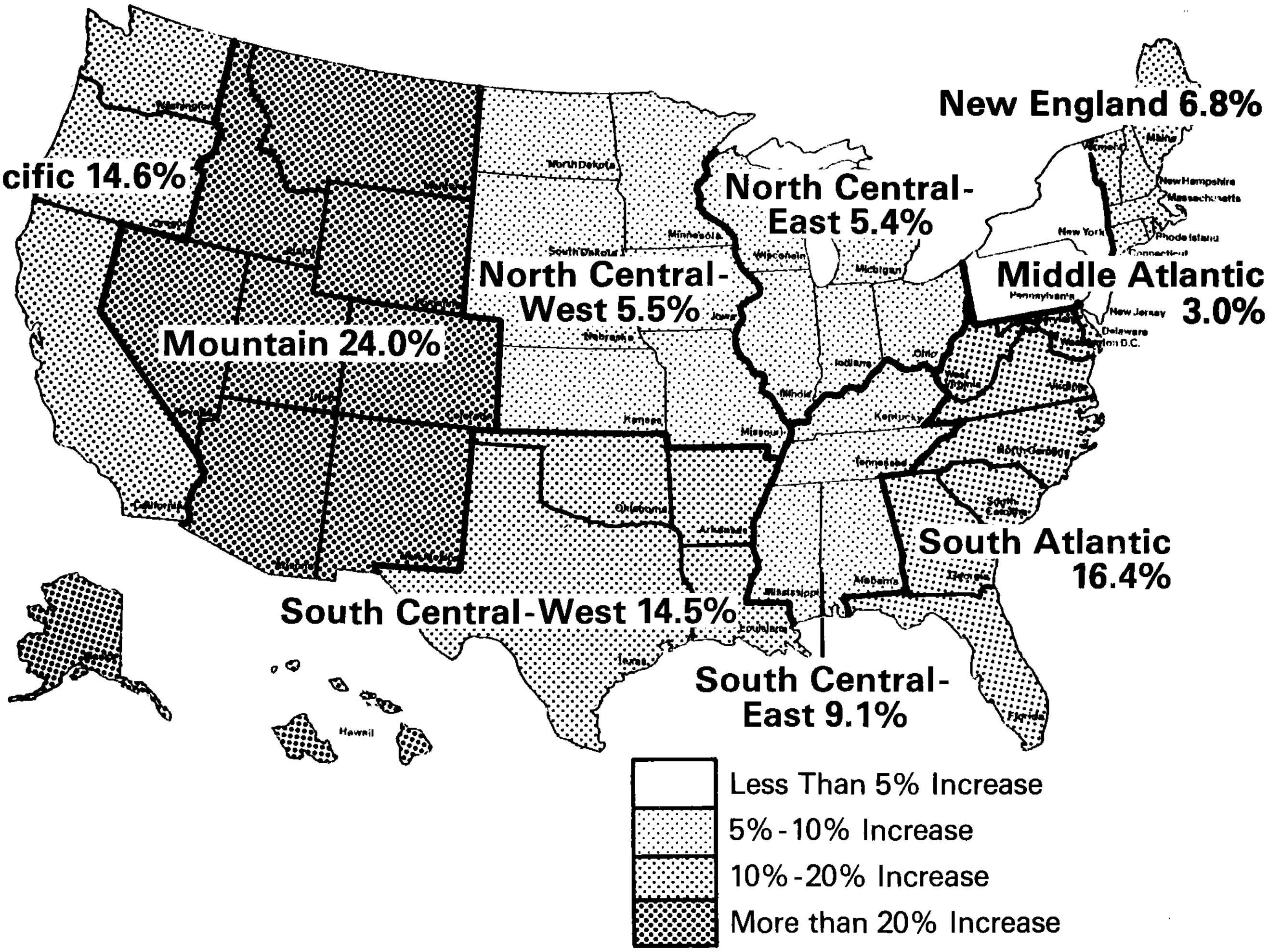
In general, solar energy systems are more labor intensive in both manufacture and maintenance/operation than alternative energy sources are. Future trends in employment and unemployment, labor relations, unionization, etc., should have an important influence on solar development. While unemployment remains a problem, the labor-intensive nature of solar technology should encourage solar development. On the other hand, if demographic trends lead to a

Figure 6-1. VALUE OF FOREIGNERS' PRIVATE INVESTMENT IN THE UNITED STATES



Source: *U.S News & World Report* (Feb. 13, 1978); U.S. Department of Commerce; 1977 estimate by USN & WR Economic Unit.

Figure 6-2. UNITED STATES POPULATION GROWTH BY REGION, 1977-87



Source: *U.S. News & World Report* (May 30, 1977); U.S. Bureau of the Census.

nearly stable labor force, the relative scarcity of labor could make solar systems less attractive than other options or could tend to favor relatively less labor-intensive solar technologies.

Resources

Solar systems generally are intensive in their use of construction materials. Though many of the required materials are fairly abundant (steel, aluminum, glass), the intensity of need may affect the scope of solar development. Some solar technologies require substantial quantities of relatively scarce materials; e.g., a single OTEC plant may require more titanium than is currently consumed annually by the United States. On the other hand, the "fuel" source for solar technology is virtually unlimited and free. Thus, the relative costs of fossil fuels and specific materials will affect the pace and form of future solar development.

SOCIAL FACTORS

Population

If present conditions of mortality, fertility, and migration persist, the size of the U.S. population will continue to grow for the next six decades or more. Migration accounts for a growing share (approximately ⅓) of population increase, and illegal immigration has become an urgent national concern. The distribution of population continues to shift from the North and East to the South and West (See Figure 6-2), with a majority of America's population expected to be residing in the so-called "sun belt" by 1980. The historic trend of rural to urban migration now has reversed. The decline in American fertility is leading to an increase in the average age of the population. By the beginning of the 21st century, one American in eight will be over age 65, and there will be one retiree for every two workers.[8] (See Figures 6-3 and 6-4) These demographic trends will both influence and to some extent be influenced by the marketing, distribution, and application of solar technology.

Lifestyle

Trends in the American lifestyle will have a powerful relation to the extent and nature of solar development. Futurist Alvin Toffler has remarked, "the notion that we can design an energy system independent of family structure, independent of epistemology, is

Figure 6-3. AGE STRUCTURE OF THE UNITED STATES POPULATION

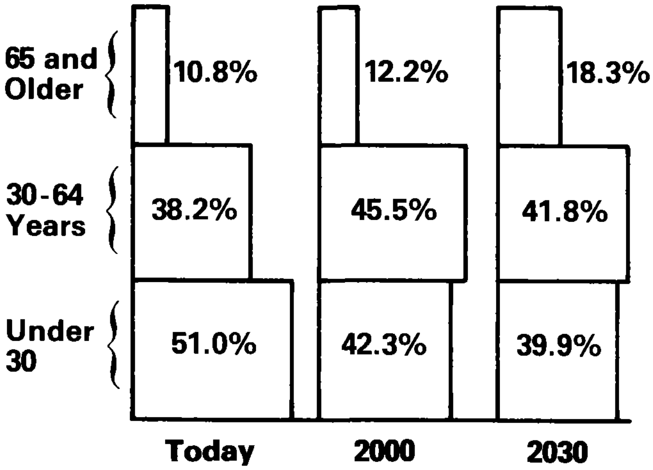
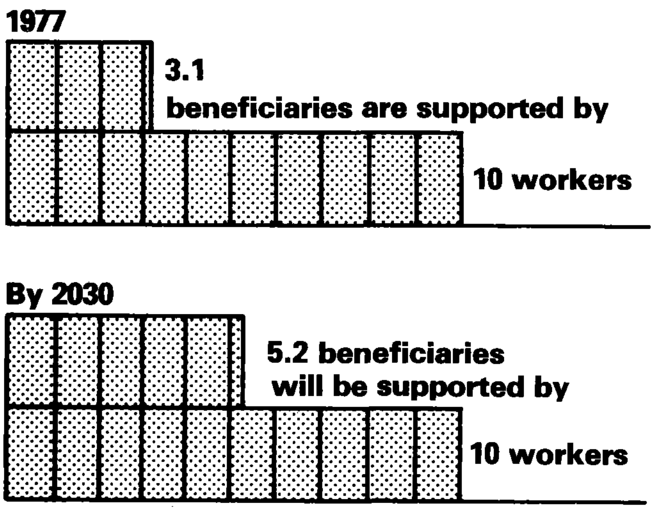
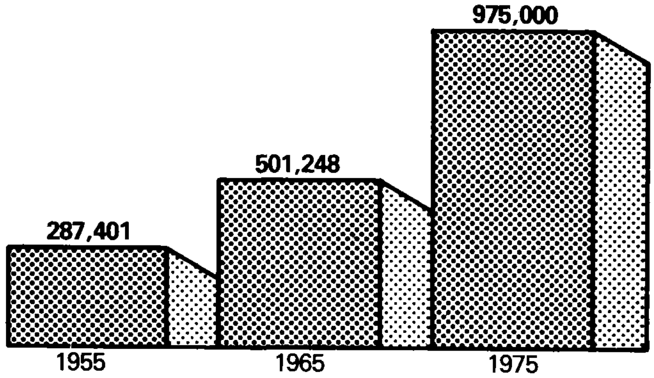


Figure 6-4. CHANGING SOCIAL SECURITY BURDEN



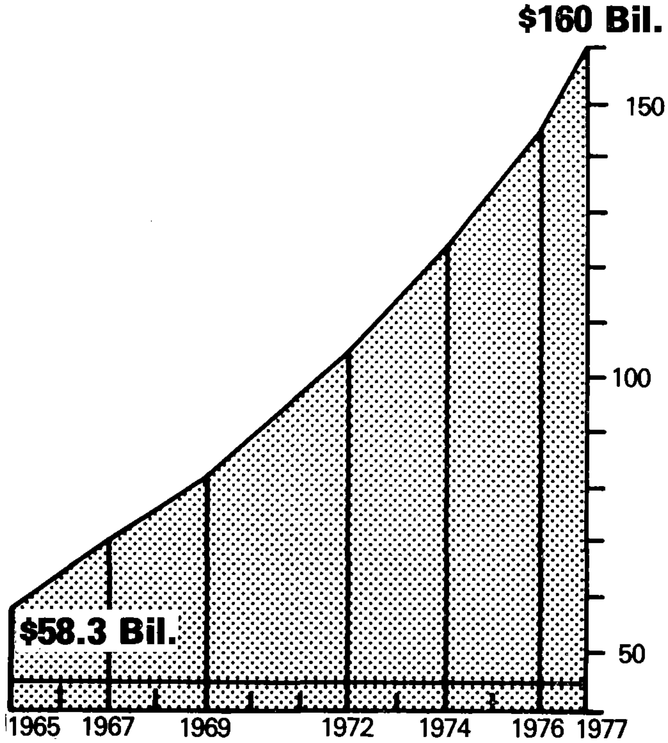
Source: *U.S. News & World Report* (Oct. 3, 1977).

Figure 6-5. BACHELOR'S DEGREES AWARDED IN THE UNITED STATES



Source: *U.S. News & World Report* (Jan. 16, 1978); plus: See original.

Figure 6-6. OUTLAYS FOR SPORTS, TRAVEL, OTHER RECREATIONAL ACTIVITIES



Source: *U.S. News & World Report* (Feb. 21, 1977); estimates by USN & WR Economic Unit Based on Government and industry data.

naive."[9] Patterns of work, education, leisure, marriage and its alternatives, family and social grouping, homemaking, and community relations will dictate how, when, where, why, and by whom solar energy is used in the future. (See Figures 6-5, 6-6, and 6-7)

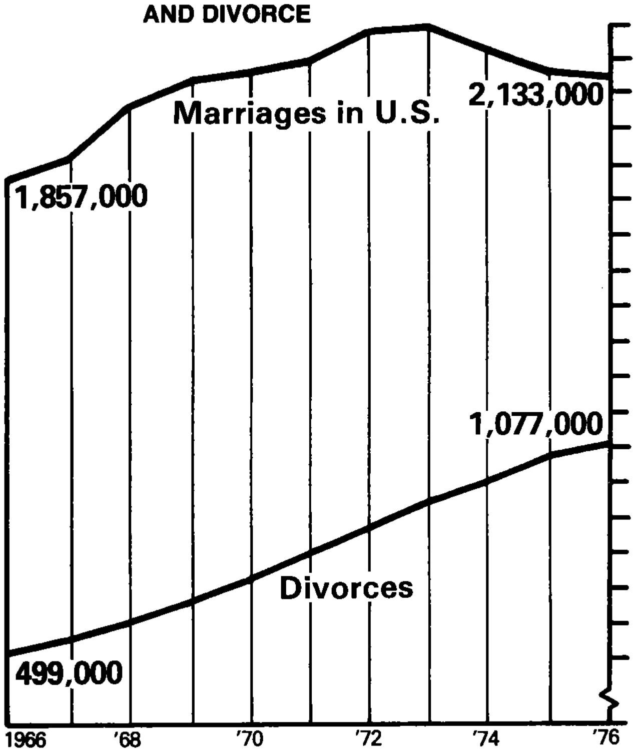
Centralization/Decentralization

The issue of political and economic centralization or decentralization is as old as the United States itself. Recently, a body of opinion has developed in the United States which views the present level of centralization of political and economic control as excessive and which actively seeks decentralization.[10] Some symptoms of this "new mood" are the recent reversal of rural to urban migration; the increased popularity of home-grown food and do-it-yourself car repairs and home improvements, the planned reduction in the proportion of total GNP devoted to Federal spending and the relatively more rapid growth of state and local governments vis-a-vis the Federal Government; state, regional, and local "goals" projects which attempt to define long-range objectives at a subnational level.

Whether the present interest in decentralization will become a dominant national trend is not yet clear; but, in any event, its impact on solar development will be profound. Significantly, solar is the only energy source presently available which can be organized economically on *either* a centralized or decentralized basis.

The possibility of individual or small group ownership of solar

Figure 6-7. UNITED STATES TRENDS IN MARRIAGE AND DIVORCE



Ratio went from 3 divorces per 10 marriages in 1966 to 5 divorces per 10 marriages in 1976.

Note: Divorces' total includes annulments.

Source: *U.S. News & World Report* (July 25, 1977); U.S. Department of Health, Education and Welfare.

systems is an attractive feature for people who favor energy decentralization.

Values

The values, goals, preferences, ideals, and ethics of the American people will be a powerful determinant of solar energy development. For example, the use of solar water heating requires a backup energy source to have both reliable service and a reasonably sized solar system. "Reliable" means that hot water is available whenever desired, independent of solar availability. If values changed so that hot water availability most of the time (e.g., 75%) were acceptable and the use of hot water were coordinated with solar availability, solar hot water heating would be much more attractive economically.

There are numerous other examples of value choices which would dramatically affect use of solar energy compared to other energy options. Because solar energy is qualitatively so different from conventional energy sources, the fullest potential use of solar in the United States may not be realized without substantial changes in American values and goals.[11]

Pluralism

The diffusion of solar technology will be influenced by how solar energy systems interact with the future relations among subgroups of the American population: rich and poor, black and white, anglo and hispanic, male and female, urban and rural, etc.

Education/Communication

Various recent surveys show clearly that the American public is poorly informed of the most elementary aspects of the nation's energy situation; a majority is unaware that the United States depends heavily on oil imports to meet its energy demands.[12] The development of solar energy will require (a) training of the skilled labor required by a new industry and (b) education to increase public understanding of energy problems and alternative energy sources. The future evolution of education and communication systems will determine how well these needs are met and will have an important influence on solar system acceptance.

Technocracy

"The post-industrial society involves the extension of a particular kind of rationality associated with science, technology, and economics. When applied to politics, this rationality becomes technocratic, and inevitably it creates a populist reaction."[13] As the technology of modern society has become more sophisticated and complex, social decisions tied to technology have gravitated away from democratic actors (e.g., legislators, stockholders, union members, voters), and toward technical specialists, and in some cases, automata.[14] Whether this trend will continue or be reversed by some popular reaction cannot be foreseen, but the outcome will have a powerful effect on the scope and form of solar development.

ENVIRONMENTAL FACTORS

Climate

With the exception of solar power satellite systems, the solar resource is highly dependent on climate conditions. The reliability of solar power will depend on the stability of climate conditions over periods of decades, at least. However, some researchers now believe that the world's climate for the past several decades has been unusually favorable and that the climate may now be changing to a new, perhaps more unstable, and generally less favorable norm.[15] Record-breaking climate conditions in several parts of the world in recent years constitute some evidence that a long-term change in climate is occurring. If so, the implications for the future development of solar technology could dominate traditional economic decisionmaking.

Waste Heat

Solar systems use energy which is already entering the biosphere and convert some of it directly to a useful purpose. At a small scale of application, solar systems tend to be neutral as far as waste heat is concerned. That is, about the same amount of heat is left behind by the solar system as would have been deposited if the solar system were not there. There are local effects, and if there are changes in the reflectivity of the solar plant area compared to the ground or rooftop, this will cause a net heating or cooling effect. At a large scale of application, solar systems could involve the transport of substantial quantities of energy from one location to another, leading to local heating and cooling and possible global climate impacts. By contrast, fossil or nuclear energy sources add all the energy they generate to the biosphere. The magnitude of that energy released now causes weather modification in certain areas. Global climate effects from heat pollution may occur within a hundred years at current energy use growth rates. The extent to which concern over heat pollution affects public policy and business planning will affect acceptance of solar technology.

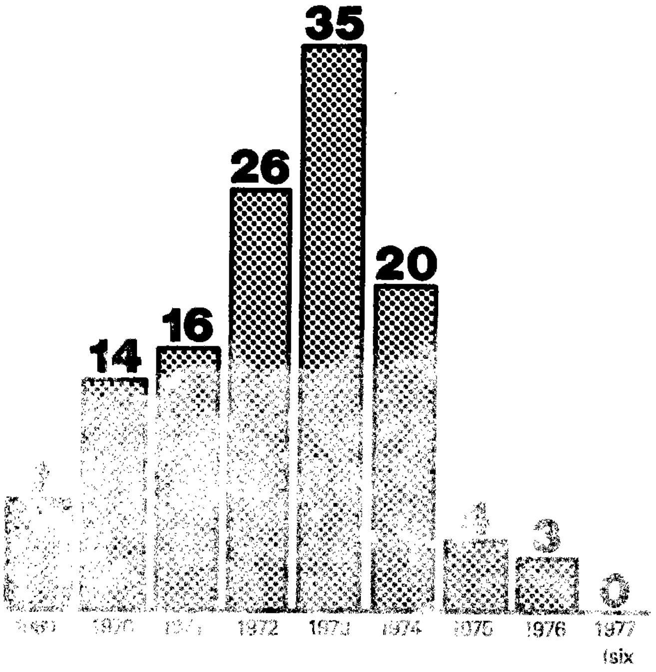
Carbon Dioxide

Some researchers believe that further expansion in the use of fossil fuels as an energy source will add so much CO_2 to the atmosphere that catastrophic climate effects will result.[16] Not enough is now known about the dynamics of climate to be sure what the net result of this CO_2 effect will be when combined with other phenomena such as sunspot activity, atmospheric particulate material, etc. The CO_2 generated by fossil fuel combustion may contribute to the melting of the polar ice caps or may accelerate the beginning of a new ice age. If further research indicates that a major hazard exists from the expanded use of coal and other fossil fuels, one result could be much more rapid development of solar technology.

Nuclear Wastes and Accidents

The problem of disposing safely of radioactive wastes from the nuclear power cycle has yet to be solved. The potentially catastrophic consequences of a major nuclear power accident, however improbable, continue to affect public acceptance of nuclear systems. In spite of claims of the economic benefits and feasibility of nuclear power, reactor sales have sharply declined. (See Figure 6-8.) If no economical solutions can be found, solar energy may become more attractive for some applications of nuclear power.

Figure 6-8. NUCLEAR POWER PLANTS PURCHASED BY UNITED STATES FIRMS



[illegible] world have to be placed in the next 15 years to meet NEP [illegible]

[illegible] World Report; basic data: Industry sources

Proliferation and Terrorism

President Carter has made limiting the further proliferation of nuclear weapon technology a major goal of his Administration. So far, no way has been found to separate the technical capability for nuclear power from the technical capability for nuclear weapon-making.[17] If nuclear safeguards break down, leading to the violent use of nuclear materials by "crazy states,"[18] or terrorist or criminal organizations, the effect on future energy developments will be dramatic. Also, a wave of terrorist activity has been sweeping the world. Terrorist acts increasingly are being committed not only by radical groups seeking political goals but by criminal organizations seeking profit through extortion. If these trends continue, a growing concern will be the vulnerability to attack of highly centralized and possibly hazardous energy facilities—e.g., nuclear, hydroelectric, liquified gas. The way the problems of proliferation and terrorism are treated will affect solar energy development.

Land Use

Some solar systems can be used on rooftops and have no additional land use impact. However, solar plants will require large amounts of land compared to the generating site land use of conventional power. For example, a 1000 MW solar electric plant would require about 33km² (13 mi²) of land. However, the solar land requirement is similar to coal when the land used for mining is considered. This aspect of solar energy may bring it into conflict with alternate land use and affect its application in certain areas. On the other hand, the total land area required even for large scale use of solar energy is relatively modest. The sunlight falling on about 2% of the U.S. land area could supply (at 10% conversion efficiency) all of America's present energy consumption; by comparison, about 17% of U.S. land is presently being cultivated (pasture and grazing land brings the total near 50%), and about 8% is urbanized. (See Figure 6-9.)

Energy System Health Impacts

Early studies indicate that solar electric energy systems may have nearly two orders of magnitude (50X) lower health effects than an advanced "clean" coal system. Also, solar systems may have about five times lower "average" health effects than a light water nuclear reactor system.[19] Health effects are always a matter of public concern; if the present trend of rapidly rising health care costs continues, health impacts of alternate energy systems could strongly influence solar development.

Other Environmental Impacts

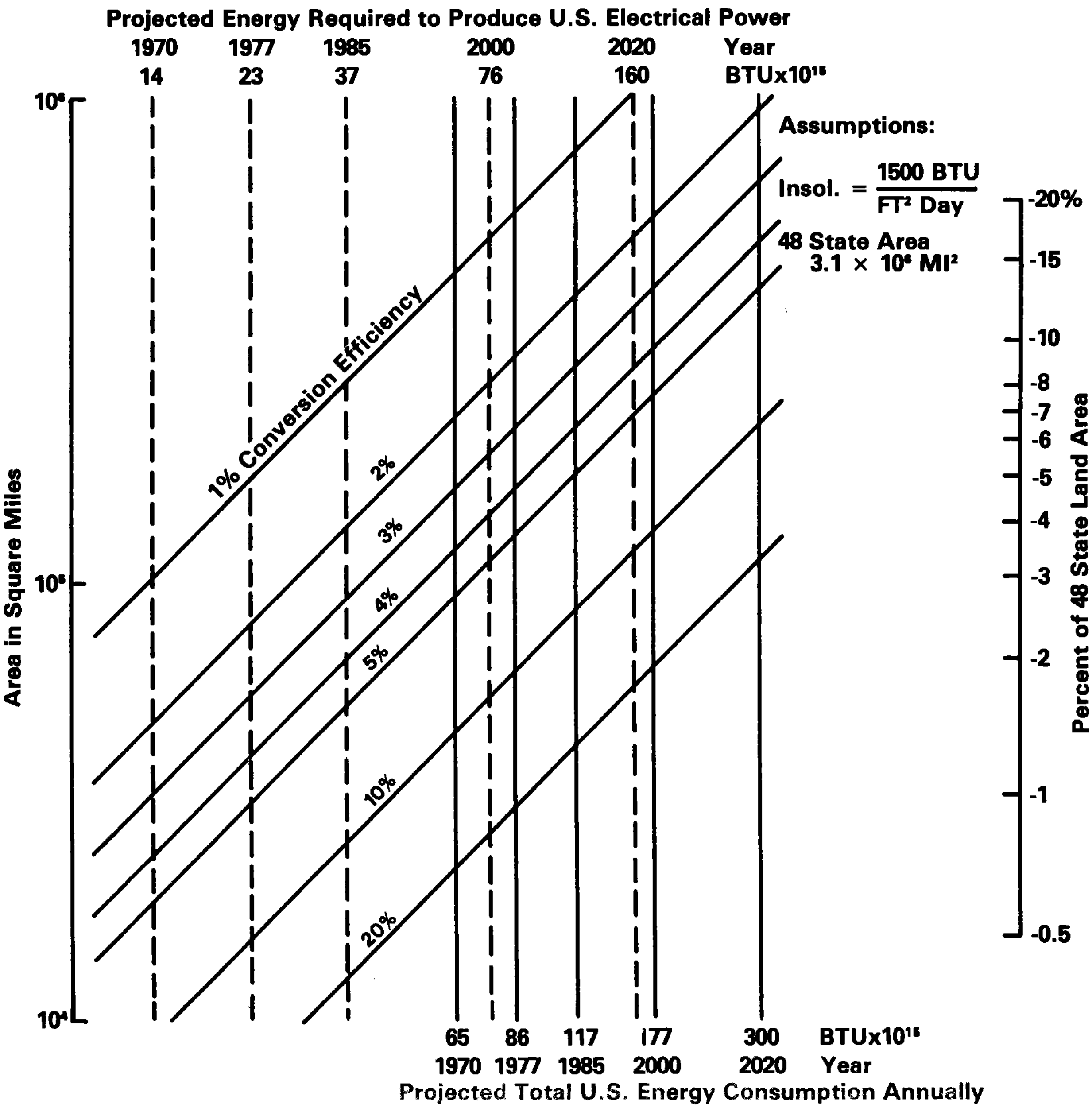
In general, the relative impacts of solar energy sources on air and water quality, wildlife, visual aesthetics, etc., will have a major influence on the future development and diffusion of solar energy technologies.

INTERNATIONAL ISSUES

Oil Politics

The international politics of petroleum obviously will have an extremely important impact on the future of solar and other energy

Figure 6-9. AVAILABILITY OF SOLAR ENERGY VS. LAND AREA



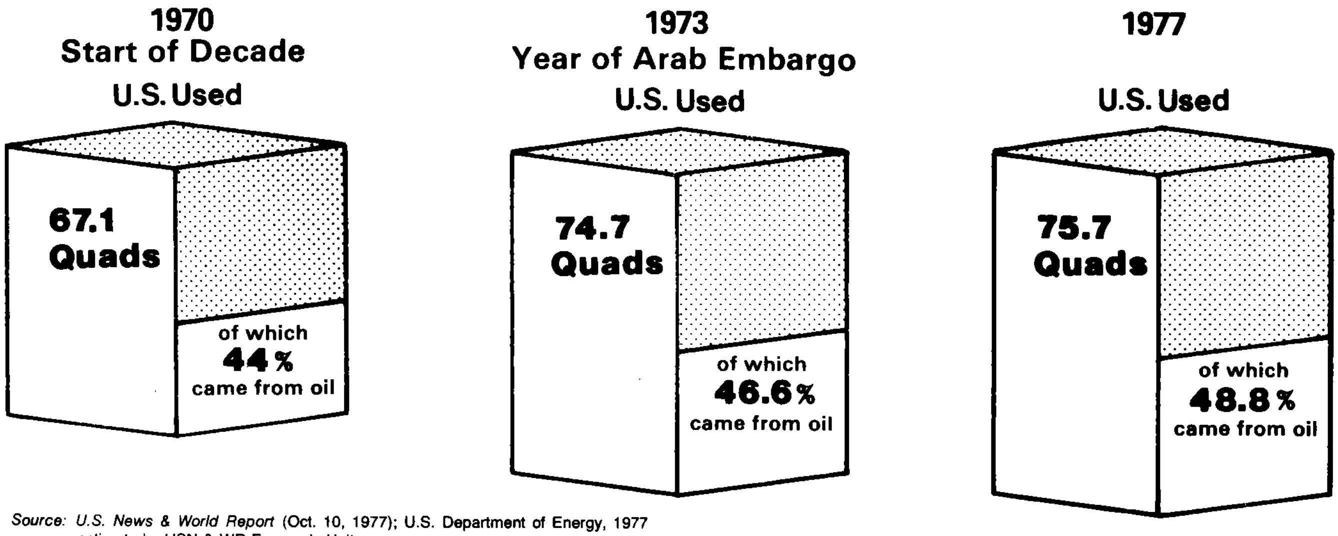
Source: NSF/NASA Solar Energy Panel, An Assessment of Solar Energy as a National Energy Resource, December 1972, p. 29.

sources. The behavior of the Organization of Petroleum Exporting Countries (OPEC) will be the major determinant of world energy prices for decades to come. Unless the United States can limit and reduce its reliance on imported oil, the nation will become increasingly vulnerable to any instability or crisis in the Middle East. (See Figures 6-10 and 6-11.) Studies by the CIA and the MIT "WAES" project indicate a worldwide shortage of oil (a growing gap between international demand and supply) beginning in the early to middle 1980s. (See Figure 6-12.)[20] The nation's perception of and interest in solar energy will be closely tied to the U.S. response to the world oil problem.

LDCs

At least two analysts believe that the less developed countries (LDCs) may be the major world market for solar technology in the near- to middle-term future.[21] These countries are generally better endowed with solar (including wind, hydro, biomass, and potentially OTEC) than with other, conventional energy resources. And the small scale, decentralized, simple, and durable features of some solar technologies make them more appropriate to the needs of most LDCs. The interest of LDCs in solar development may determine the significant early markets for solar energy as well as the scope and structure of the world solar energy market further in the future.

Figure 6-10. PETROLEUM CONSUMPTION BY THE UNITED STATES IN QUADS (10^{15} Btu)



Source: *U.S. News & World Report* (Oct. 10, 1977); U.S. Department of Energy, 1977 estimate by USN & WR Economic Unit.

International Monetary System

Partly as a result of the rapid increases in the world price of oil in the early 1970s, the international monetary system has become increasingly strained and unstable. (See Figure 6-13.) LDC indebtedness has grown rapidly with the escalating cost of oil imports. The value of the U.S. dollar declined steadily through 1977, reflecting a lessened demand for United States food exports and growing uncertainty about the ability of the United States to limit its dependence on foreign oil.[22] One symptom of monetary malaise is a recent increase in international bartering of goods and commodities, circumventing the monetary system altogether.[23] Protectionist pressures are growing in the OECD nations. Where these trends will lead is unclear. However, the future of the international monetary system will inevitably affect both the domestic development of solar energy and the world market for solar technology.

Population and Food

The population of the earth is increasing at a rate of about 2% a year; the populations of many LDCs are growing at rates in excess of 3% a year. If these trends continue, the population of the world will double in about 35 years, and that of some poor nations in only 20 years. In the absence of more effective efforts in population control, one result will be an ever-worsening crunch between population and food supply in many parts of the world. The implications of this tragic trend for solar development could be significant. Some solar applications (e.g., irrigation pumping, food drying) could help continue the growth of agricultural output until population growth can be checked. On the other hand, the development of some solar technologies (e.g., biomass for fuel) could be limited if these conflict with food production.[24]

RESEARCH AND DEVELOPMENT

Learning Curves

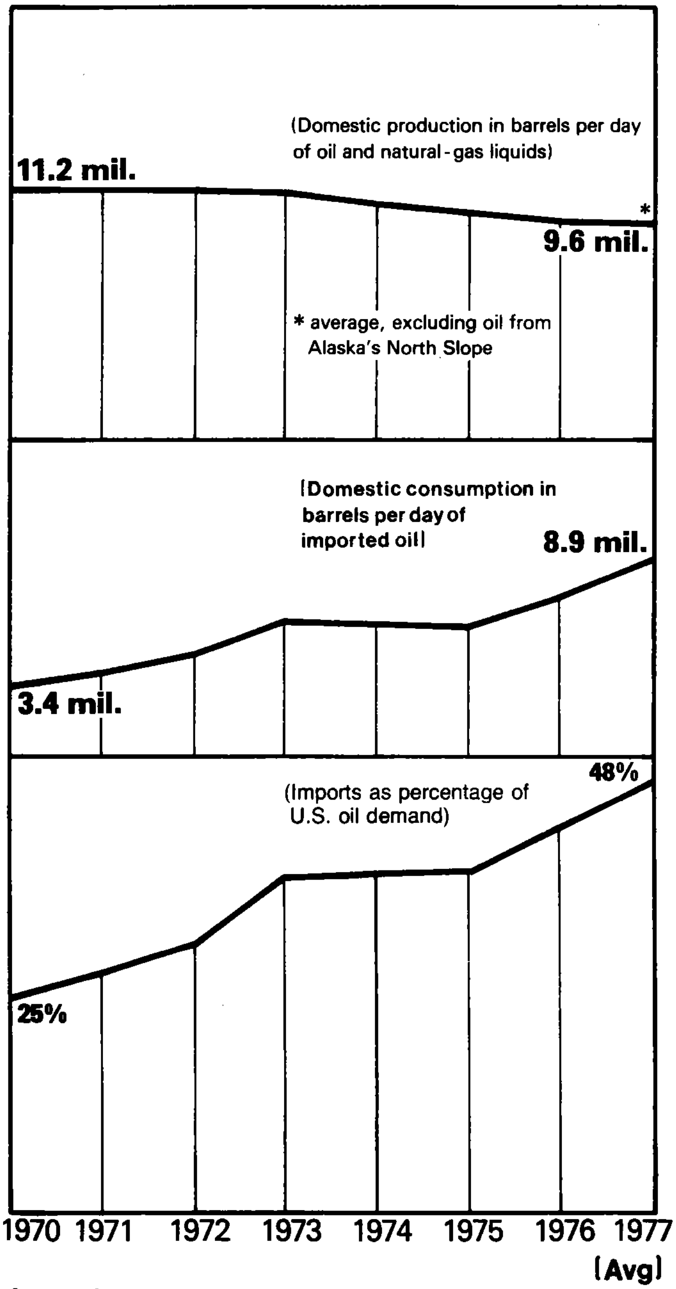
As producers gain experience with a new technology, generally the costs of production are reduced while the quality of the product is improved. This process can be described by a hyperbolic type of curve called a "learning" curve. The learning curve indicates both when a new technology is likely to be competitive in the market place, and also how competitive the technology may become. The actual learning curve for a new technology cannot be predicted, but can be induced by comparison with historical learning curves of similar technologies and by careful mass production cost projection of specific designs believed to have commercial potential. The expected learning curve for new solar technologies may be highly influential on both public and private planning for solar development.[25]

Breakthroughs

Some technologies do not develop through the continuous process of the learning curve but experience sudden and rapid improvement—i.e., a "breakthrough." Breakthroughs are sometimes the result of accident or a spin-off from a line of research unrelated to the final application of the new technology. Although breakthroughs are necessarily unpredictable, their potential consequences often can be anticipated.[26] Some potential breakthroughs which could have a dramatic effect on future solar development would be:

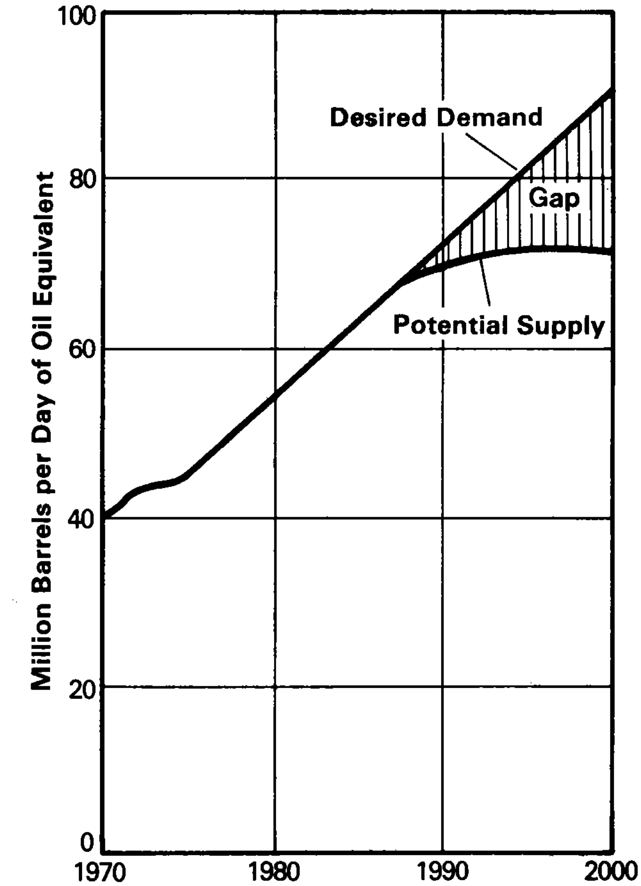
- invention of a cheap, simple, and efficient photovoltaic collector which could be easily mass produced;
- development of cheap and efficient photobiochemical materials;
- genetic manipulation of plants leading to a highly productive biomass source which would use marginal land unsuitable for food production;
- compact, highly efficient energy storage and transmission media;

Figure 6-11. INCREASING UNITED STATES DEPENDENCE ON IMPORTED OIL



Source: *U.S. News & World Report* (Oct. 10, 1976); U.S. Department of Energy.

Figure 6-12. OIL DEMAND AND SUPPLY IN THE WORLD OUTSIDE COMMUNIST AREAS



Projection based on assumptions of high economic growth rate, rising energy price, strong government response, and coal (rather than nuclear) as replacement fuel.

Source: *Energy: Global Prospects 1985-2000,* Report of the Workshop on Alternative Energy Strategies, C.L. Wilson, Director (New York: McGraw-Hill, 1977).

- development of a cheap, efficient, small heat engine with long-life capability for use with distributed collectors.

Major breakthroughs in other energy technologies (e.g., fusion, nuclear breeders, oil shale) also would have an important impact on future solar development.

Federal R&D Program

Obviously, a major influence on future solar development will be the Federal program for investing billions of dollars of public funds in energy R&D. The priority of solar energy in relation to other energy sources, and the strategy for developing specific solar technologies, will have an important effect on solar energy's future.

POLICY

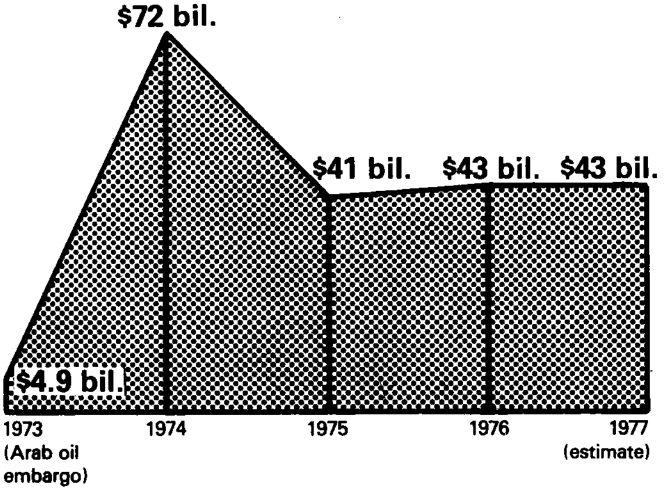
Federal Energy/Economic Policy

The future of solar energy in the United States will be heavily influenced by the entire complex of Federal policies affecting energy and the economy. The Department of Energy's biannual National Energy Plan will identify energy goals and will affect the scope and intensity of Federal efforts in solar development.

State and Local Policies

The policies of state and local governments will powerfully influence future solar development, possibly more so than will Federal

Figure 6-13. ANNUAL BALANCE-OF-PAYMENTS SURPLUS BY MEMBERS OF THE ORGANIZATION OF PETROLEUM EXPORTING COUNTRIES



Source: *U.S. News & World Report* (May 9, 1977); U.S. Department of the Treasury.

policies. Many policy areas vital to solar development are primarily within the jurisdiction of state and local governments, e.g., land use, housing and buildings, transportation, public utilities. To a large extent, state governments have become the primary innovators and leaders in the development of public policy; for example:

- Nebraska's "gasohol" program, requiring the use of 10% alcohol mixed with gasoline;
- Colorado's "sunshine" (open public meetings) law;
- California's air pollution control and solar tax credit programs;
- land use planning in Hawaii, Vermont, and Florida;
- Oregon's "bottle bill," to encourage recycling of beverage containers by requiring a deposit.

Local governments, too, have been the source of innovative public leadership, e.g., Seattle's "CPR" (cardiopulmonary resuscitation) program; Davis' (Calif.) land use program; Lowell's (Mass.) urban redevelopment program. The cutting edge of future solar development in the United States may well be found in the efforts of state, local, and regional agencies.

Notes

[1]J. Reuyl, et al., *Solar Energy in America's Future: A Preliminary Assessment*, SRI International, January 1977 (prepared for the Environmental and Resource Studies Branch, Division of Solar Energy, US-ERDA).

[2]See: Duane Chapman, "The Problem of Growth and Monopoly," Testimony for Subcommittee on Energy and the Environment, Committee of Interior and Insular Affairs, U.S. House of Representatives, on *Public Energy Competition Act*, Hearings, September 1977.

[3]See: Peter F. Drucker, *The Unseen Revolution: How Pension Fund Socialism Came to America* (New York: Harper & Row, 1976). Also, "Who Owns American Industry? The Shifts Underway," *U.S. News & World Report*, July 18, 1977, pp. 70-71.

[4]See: E. Conine, "Foreigners on a Buying Spree in America," *Denver Post*, February 28, 1978. Also: "Why Foreigners Pour Money Into U.S.," *U.S. News & World Report*, February 13, 1978, pp. 79-80.

[5]E.R. Bagley, *Beyond the Conglomerates: The Impact of the Supercorporation on the Future of Life and Business* (New York: AMACOM, 1975).

[6]R.L. Heilbroner, *Business Civilization in Decline* (New York: Norton, 1976).

[7]E.L. Allen, et al., *U.S. Energy and Economic Growth, 1975-2010*, Institute for Energy Analysis/Oak Ridge Associated Universities, No. ORAU/IEA-76-7, September 1976.

[8]See: "Big Changes in How People Live—New Official Look," *U.S. News & World Report*, January 16, 1978, pp. 42-44. Also: "End of Youth Culture-Changes It Will Bring," *U.S. News & World Report*, October 3, 1977, pp. 54-56.

[9]A. Toffler, Seminar at Solar Energy Research Institute, September 22, 1977.

[10]For example, see the following: A. Lovins, *Soft Energy Paths: Toward a Durable Peace* (Cambridge, Mass.: Ballinger; 1977); D. Hayes, *Rays of Hope* (New York: Norton, 1978); Wm. Ophuls, *Ecology and the Politics of Scarcity* (San Francisco: Freeman, 1976); "Voluntary Simplicity, A New Life-Style?", *The Futurist*, August 1977.

[11]See: C.R. Nixon, "Problems, Appreciations, and Decisions," presented at Second International Conference on Alternatives to Growth, The Woodlands, Texas, October 2-4, 1977. Also: Lovins, *Soft Energy Paths* and Reuyl, et al., *Solar Energy in America's Future*.

[12]L. Fishman, "Public Perceptions of the Energy Crisis," *Resources*, 57, January-March 1978, p. 2.

[13]Daniel Bell, "The Post-Industrial Society," in H. Kahn (ed.) *The Future of the Corporation* (New York: Mason & Lipscomb, 1974), p. 41.

[14]For example, most bank loans are now evaluated by a computerized scoring system which largely determines whether or not a loan will be approved. See: "How Lenders Size You Up," *Changing Times*, January 1978, pp. 37-39.

[15]S.H. Schneider, *The Genesis Strategy: Climate and Global Survival* (New York: Plenum, 1976); R.A. Bryson, *World Climate and World Food Systems III; The Lessons of Climatic History*, Institute of Environmental Studies, University of Wisconsin, Report 27, November 1974; B. Steiger, *A Roadmap of Time* (Englewood Cliffs, N.J.: Prentice-Hall, 1975).

[16]See: G.M. Woodwell, "The Carbon Dioxide Question," *Scientific American*, January 1978. Also: "Is Energy Use Overheating the World?" *U.S. News & World Report*, July 25, 1977.

[17]For a thorough analysis of the proliferation problem, see: M. Willrich and T. B. Taylor, *Nuclear Theft: Risks and Safeguards* (Cambridge, Mass.: Ballinger, 1974.

[18]See: Yehezkel Dror, "Crazy States: Nations that Go Berserk," *The Futurist*, VII, 5, October 1973, p. 215.

[19]R. Caputo, *National Comparative Assessment of Orbital and Terrestrial Central Power Systems*, Jet Propulsion Laboratory, Final Report, No. JPL 900-780, March 1977. A system is considered to be from fuel and material mining to end of plant operation. Most of the nuclear health impact is derived from the low probability-high impact catastrophic accident. This event is spread over the life of the many nuclear plants to arrive at average values.

[20]*The International Energy Situation: Outlook to 1985*, Central Intelligence Agency, No. CIA ER 77-10240 U, April 1974; C. Wilson, *Energy: Global Prospects 1985-2000* (New York: McGraw-Hill, 1977).

[21]D. Hayes, *Energy for Development: Third World Options*, Worldwatch Institute, Worldwatch Paper 15, December 1977; A. Hammond, "An International Partnership for Solar Power," *Science*, 197, 4304, August 12, 1977, p. 623.

[22]See: "Can the Dollar Be Saved?" *U.S News & World Report*, March 13, 1978, p. 41.

[23]Even the United States has discussed bartering weapons for oil with Middle East nations.

[24]See: E. Eckholm, *The Other Energy Crisis: Firewood, Worldwatch Institute, 1975.*

[25]An important study which projects the potential future market for one solar technology based on a learning curve is *DOE Photovoltaic Energy Conversion System Market Inventory and Analysis,* Federal Energy Administration Task Force on Solar Energy Commercialization, 1977.

[26]Science fiction writers are known for anticipating technological breakthrough long in advance. For example: Jules Verne—nuclear submarine; Immanuel Tsialkovski—manned space station; Arthur C. Clarke—communications satellite.

7. SOLAR SPACE AND HOT WATER HEATING

BASIC TECHNICAL DESCRIPTION

Systems and Components

Active solar energy systems used for space heating and/or hot water heating are generally characterized by the use of flat-plate solar collectors. These collectors are located on the roof or on the ground nearby. The rest of the solar system includes a storage system, control system, and a heat delivery system. Many variations of flat-plate collectors exist, and Table 7-1 indicates most possible variations in the parts of the collector. A collector design is established by a reasonable combination of these parts. One of the most common flat-plate collector designs is: fluid in tubes soldered to a metal absorber plate with a selective coating; two layers of glass cover the absorber, and fiber mat insulation is in a metal can and placed behind the absorber; the collector is stationary and tilted up from the horizontal at an angle slightly greater than the latitude angle. There are three major generic types of flat-plate solar energy systems.

HOT WATER HEATING USING A LIQUID SOLAR COLLECTOR

This is a common system and frequently seen in parts of the country such as southern California and Florida. It is a simple system and has a liquid collector generally on the roof of the building; a storage tank to hold the water; an auxiliary water heater; and the necessary piping, pumps, and control components. Figure 7-1 pictures such a solar energy water heating system. The auxiliary water heater is used for a more cost-effective system.

SPACE AND HOT WATER HEATING USING LIQUID SOLAR COLLECTORS

This system is similar to the above hot water heating system in that flat-plate collectors heat a fluid which is stored in a tank for use, in this case, for space heating as well as water heating.

Auxiliary heating, piping, pumps, and controls are also used in the system. However, there are a number of differences. First, the system is much larger (about a factor of 10), since the energy requirement for space heating plus hot water is much larger and more seasonally dependent than for hot water alone. About 400 to 600 ft^2 collectors are required for a typical home vs. 40 ft^2 for just hot water, and the storage volume is about 1000 gallons vs, about 60 gallons for a typical residence.

The liquid in the collector is subject to freezing. To overcome this, a water/ethylene glycol mixture, or a heat transfer oil, is often used; if the fluid is water, it is drained at night. If water is not used in the collectors, a heat exchanger is used to transfer the heat from the collector fluid to the water in the storage tank. If a water system is used for space heating, hot water in the storage tank can be directly circulated throughout the residence. However, if an air heating system is used, a water-to-air heat exchanger is required to heat the air with the hot stored water. Figure 7-2 describes this type of system and also shows the heat exchanger coil in the storage water for preheating the domestic hot water.

SOLAR AND HOT WATER HEATING USING AIR SOLAR COLLECTORS

In this system, which is similar to the liquid collection system, air acts as the fluid for collecting solar energy. In place of pipes, sheet metal ducting is used to circulate the air through the system. The collected heat is usually stored in a thermal pebble bed. Figure 7-3 illustrates such a system.

In addition to conventional flat-plate collectors, active solar space heating and domestic hot water systems can use unique designs which are noteworthy. Example of these include:

EVACUATED TUBE COLLECTORS

This type of advanced collector generally consists of an absorber tube or plate which carries a working fluid and is surrounded by a transparent cover tube. Some designs, including that shown in Figure 7-4, have a central, small feeder tube, and a manifold connection is made at only one end. The space between the cover and absorber tubes is evacuated to reduce heat losses to the environment.

CONCENTRATING COLLECTORS

This type of solar collector focuses incoming solar rays on an absorber surface. It is possible to use flat reflection surfaces to

Table 7-1. TYPES OF SOLAR FLAT-PLATE COLLECTORS

Types of Absorbers	1. Metal surfaces 2. Plastics 3. Cloth gauze or metal screening 4. Porous foam 5. Darkened fluid 6. Darkened glass in contact with fluid
Types of Glazings	1. Glass (single or multilayers) 2. Plastics (thin film or rigid) 3. Combinations of glass and plastic 4. Glass or plastic transparent honeycombs
Types of Fluid Receivers	1. Fluid in metal tube attached (soldered, welded, or roll-bond) to metal absorber 2. Fluid cascading down channels on absorber 3. Air passing through gauze or screen
Types of Surfaces	1. Flat black paints, oxides, enamels 2. Selective high absorptance, low emittance coatings 3. Scratched, finned, or roughened surface
Insulation	1. Fiber mat 2. Foam (plastic or glass) 3. Reflective layers 4. Vacuum in glass tube
Types of Mounting	1. Stationary tilted 2. Periodic tilt angle adjustment 3. Continuous tilt angle adjustment 4. Continuous vertical-axis rotation with constant tilt angle
Radiation Augmentation	1. Adjacent nonspecular reflective areas 2. Adjacent specular reflective areas

direct the insolation onto the absorber, or curved surfaces can focus incoming solar rays on the absorber surface. Some curved surfaces, such as the CPC (Compound Parabolic Concentrator) in Figure 7-5, can use diffuse as well as direct insolation. All concentrating collectors increase performance by tracking the sun. Even the flat reflector and low concentration ratio CPC collector should have several adjustments per year. Other concentrating collectors use continuous tracking to achieve higher concentrating ratios (>10:1) and are not normally used for low-temperature (<200°F or <93°C) hot water or space heating systems. They have one or even two axes of tracking and involve a variety of arrangements of reflective surface shapes and tracking schemes. Table 7-2 provides an extensive list of concentrating collectors, and Figures 7-6 through 7-11 indicate several design approaches.

Design Technology

The following design techniques were available during 1977 for solar space heating and domestic hot water systems. Brief descriptions are included.

FCHART is a correlation of dynamic simulation runs developed by

Figure 7-1. LIQUID SOLAR COLLECTOR—HOT WATER ONLY SYSTEM

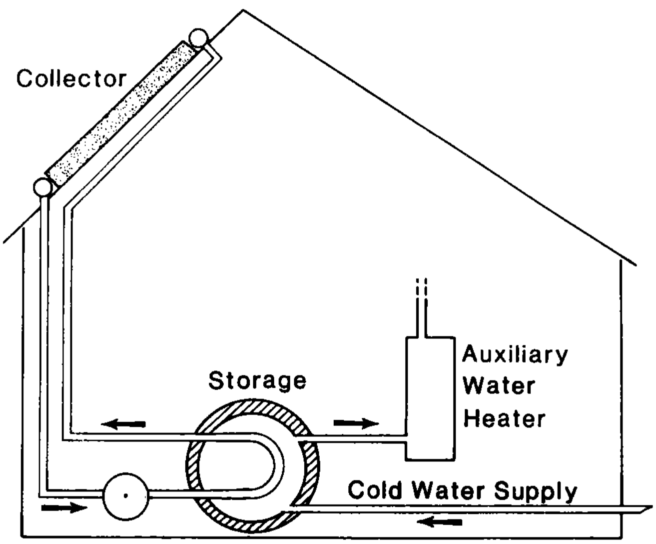


Table 7-2. TYPES OF FOCUSING COLLECTORS

Flat reflectors	1. Flat side boosters with seasonal adjustments 2. Asymmetric "V" trough flat with biannual reversing 3. Compounds parabolic concentrator (CPC) in E-W direction with several adjustments per year
Multiple flat reflectors	1. Stationary flats, moving focus 2. Individually or array sun following—one-axis tracking 3. Individual or array sun following—two-axis tracking
Single curvature reflectors using circular or parabolic cylinders	1. North-South orientation, one-axis tracking (E-W) horizontal, fixed tilt, or adjusted tilt continuous or segment reflectors 2. East-West horizontal orientation, one-axis tracking (N-S) continuous or segmented reflectors 3. Normal to sun position, with two-axis tracking
Double curvature reflectors, two-axis	1. Tracking 2. Paraboloids 3. Individual receiver attached to reflector 4. Individual or central fixed receiver 5. Spheres 6. Fixed with movable receiver 7. Individual receiver attached to two-axis tracking reflector 8. Catenaries of revolution 9. Arrays focused on one receiver 10. Arrays focused on individual receivers
Other Shapes and Composite Reflectors	1. Fresnel reflectors, cylindrical 2. Fresnel reflectors, circular 3. Truncated cones 4. Sun followed flat reflector and fixed paraboloid reflector 5. Multiple sun following flat reflectors and large fixed paraboloid
Lenses	1. Conventional cylindrical 2. Conventional circular 3. Fresnel circular 4. Fresnel strips

Klein, Beckman, and Duffie at the University of Wisconsin. FCHART is available in handbook, hand-held calculator, and interactive computer program format.

GFL, a simplified design method for solar energy space and hot water heating systems, is being developed at SERI by Lameiro and Bendt. The GFL method would be an accurate handbook approach, eliminating the need for a computer.

LASL is a graphical design technique developed at the Los Alamos Scientific Laboratory by means of comparing dynamic simulations. Results are available only for the southwestern United States.

SIMSHAC is another dynamic simulation model developed at Colorado State University.

SOLCOST is a simplified design procedure for sizing of solar heating and hot water systems. It is based upon one-day calculations for each month of the year. SOLCOST was developed by Martin-Marietta and is being validated by the Solar Environmental Engineering Corp.

STOLAR is a simplified procedure based upon a stochastic model of ambient conditions. This method was developed at Colorado State University by Lameiro and Duff.

TRNSYS is a dynamic simulation model developed at the University of Wisconsin. It is considered to be one of the most accurate models in the United States.

SIZING ESTIMATES

The following are commonly used rules-of-thumb for designing solar space heating and domestic hot water systems.

Collector area. The collector area required for meeting approximately 70% of the load with an active system equals about 1/6 to 1/4 the floor space of a well-insulated residence.

Collector tilt. Collectors should be tilted at the latitude angle, plus 10°, for space heating and at the latitude angle for hot water alone.

Storage size. Storage should be about 1.5-2.5 gallons of water per

Figure 7-2. LIQUID SOLAR COLLECTOR-SPACE AND HOT WATER HEATING SYSTEM

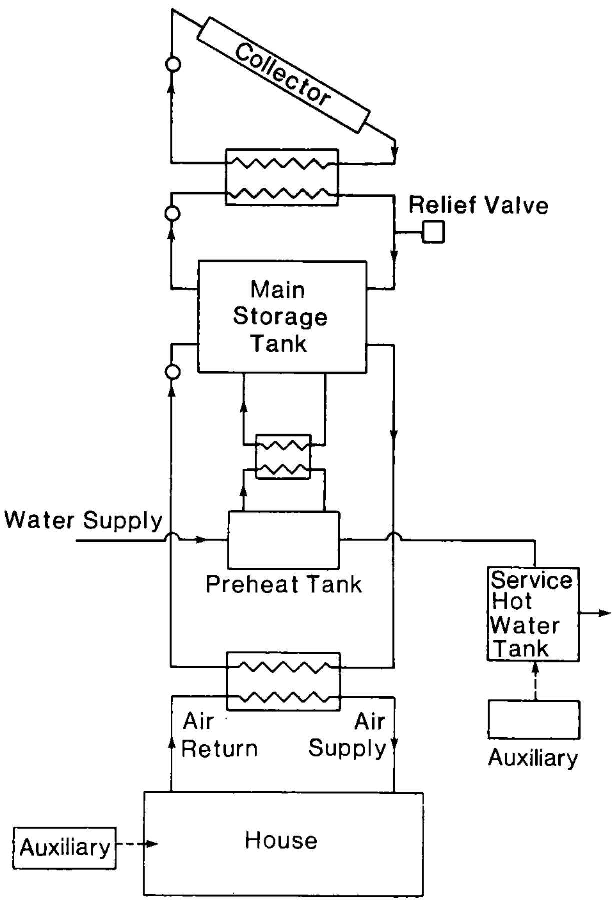
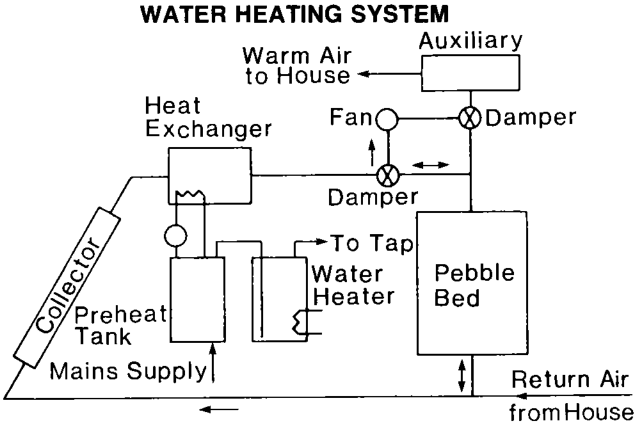


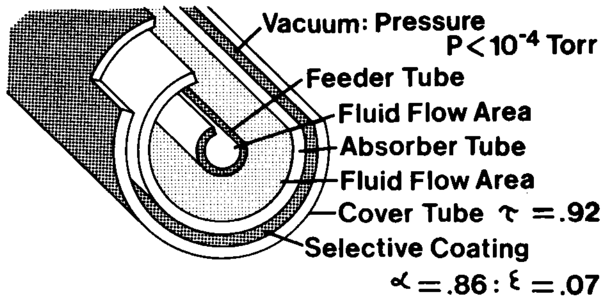
Figure 7-3. AIR SOLAR COLLECTOR-SPACE AND HOT WATER HEATING SYSTEM



square foot of collector area for a liquid system, and 40-70 pounds of rock per square feet of collector area for air systems.

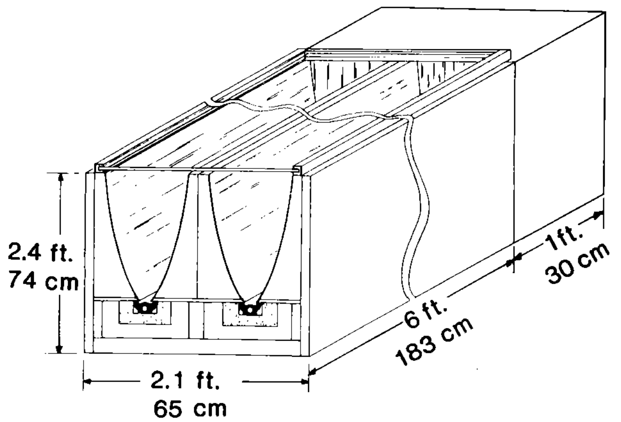
Flow rates. Flow rate to the collectors should be about 0.18-0.20 pound (mass) per minute per square foot of collector area for a liquid system, and 2 cubic feet per minute per square foot of collector area for air systems.

Figure 7-4. EVACUATED TUBE COLLECTOR



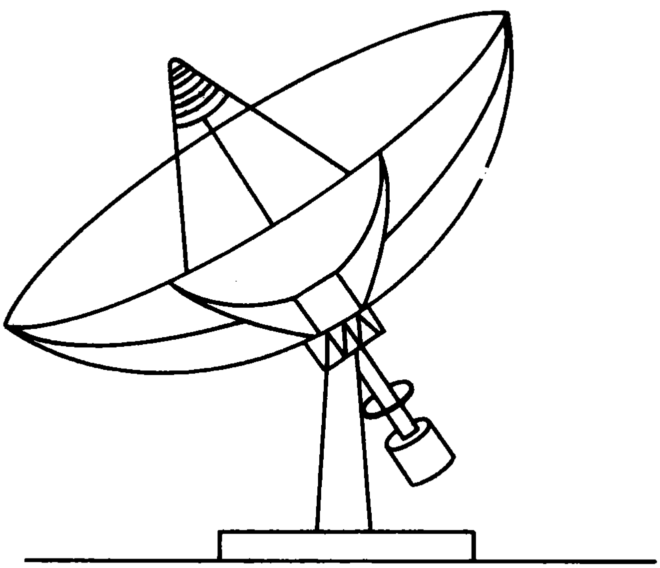
Source: Owens-Illinois SUNPAK® Collector Owens-Illinois, Toledo, Ohio.

Figure 7-5. COMPOUND PARABOLIC CONCENTRATOR



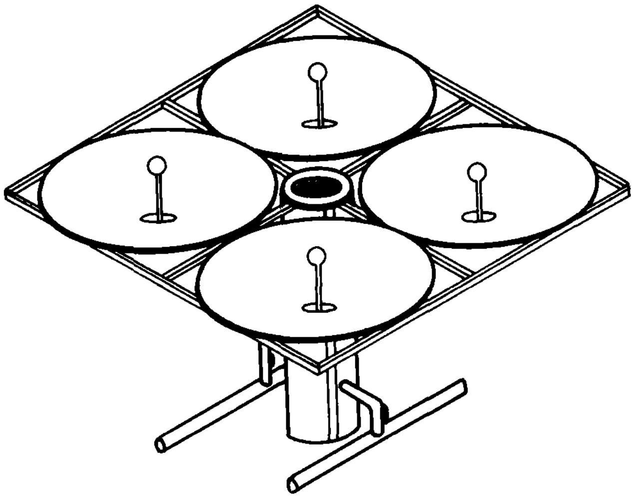
Source: Argonne National Laboratory, ANL-76-71.

Figure 7-6. PARABOLOID WITH CAVITY ABSORBER



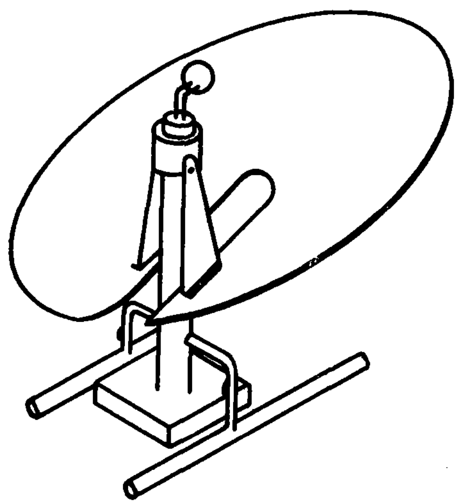
Source: Colorado State University, *Solar Thermal Electric Power Systems Report*, November, 1974.

Figure 7-7. MULTIPLE PARABOLOIDS WITH INDIVIDUAL ABSORBERS



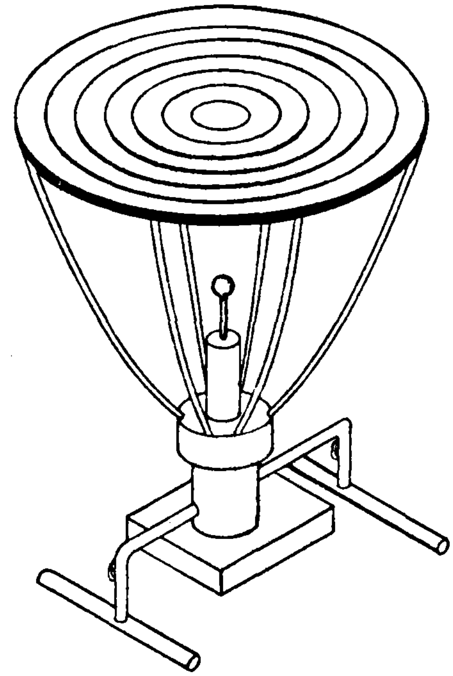
Source: Colorado State University, *Solar Thermal Electric Power Systems Report*, November, 1974.

Figure 7-8. SINGLE PARABOLOID WITH FIXED ABSORBER



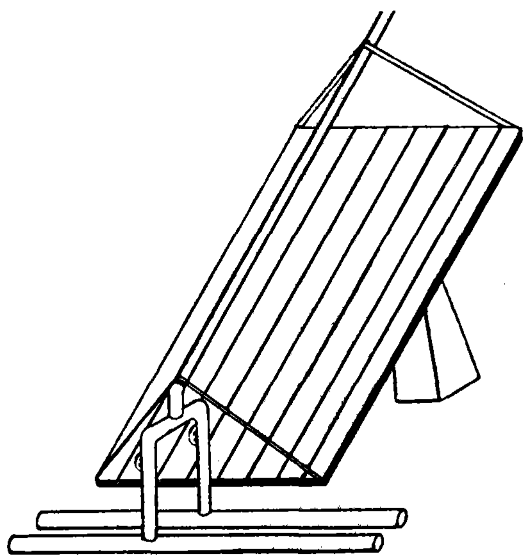
Source: Colorado State University, *Solar Thermal Electric Power Systems Report*, November, 1974.

Figure 7-9. FRESNEL LENS



Source: Colorado State University, *Solar Thermal Electric Power Systems Report*, November, 1974.

Figure 7-10. FRESNEL REFLECTOR



Source: Colorado State University, *Solar Thermal Electric Power Systems Report*, November, 1974.

GOALS AND DESCRIPTION OF FEDERAL PROGRAM

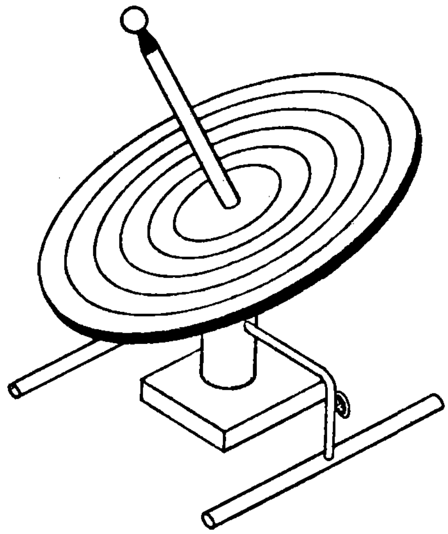
The primary goal of the Federal Solar Energy Space Heating and Domestic Hot Water program is:

> to stimulate the development of an industrial, commercial, and professional capability for the production and distribution of solar water heating, space heating and cooling systems. . . .

The primary goal is manifested in the following key objectives:

- reduce component costs;
- increase performance of components;
- demonstrate solar heating (by 1977);

Figure 7-11. CYLINDRICAL FRESNEL REFLECTOR



Source: Colorado State University, *Solar Thermal Electric Power Systems Report*, November, 1974.

- develop solar standards;
- develop performance criteria for components.

The role of various Federal agencies is summarized in Figure 7-12. Key mile-stones in the Federal program for solar heating are presented in Figure 7-13. Path descriptions for the Federal R&D effort are given in Table 7-3. The extent of the Federal demonstration program is shown in Table 7-4. Table 7-5 presents a summary of the response to the hot water initiative.

The following is an explanation of the R&D strategies for the various paths shown in the Federal R&D program.

W1: Liquid Heating Collectors

The objective of this path is to assist a small, but viable and developing solar water heater industry. To accomplish this objective, the many approaches to hot water heating will be identified. Each approach will be characterized by determining basic climate performance, materials characterization, testing, and evaluation.

In addition, each approach will be evaluated to establish methods for freeze protection, methods of integration with existing hot water systems, and cost-performance characteristics of existing marketed systems. Several specific research areas will be explored, such as:

- the question of stratification in the storage tank and how stratification is affected by the shape, type, and location of the auxiliary heater;
- novel design of appropriate heat exchangers operating at low flow rates and with small temperature drops (advantage will be taken of the fact that the structural limitations are minimal);
- the appropriate method of connecting collectors.

W2: Air Heating Collectors

The objective of this path is to determine the economic viability of the air-heating approach. The program will emphasize identification of the performance characteristics of various collectors and climates. Materials work will be directed principally toward

Figure 7-12. ROLES OF OTHER FEDERAL AGENCIES

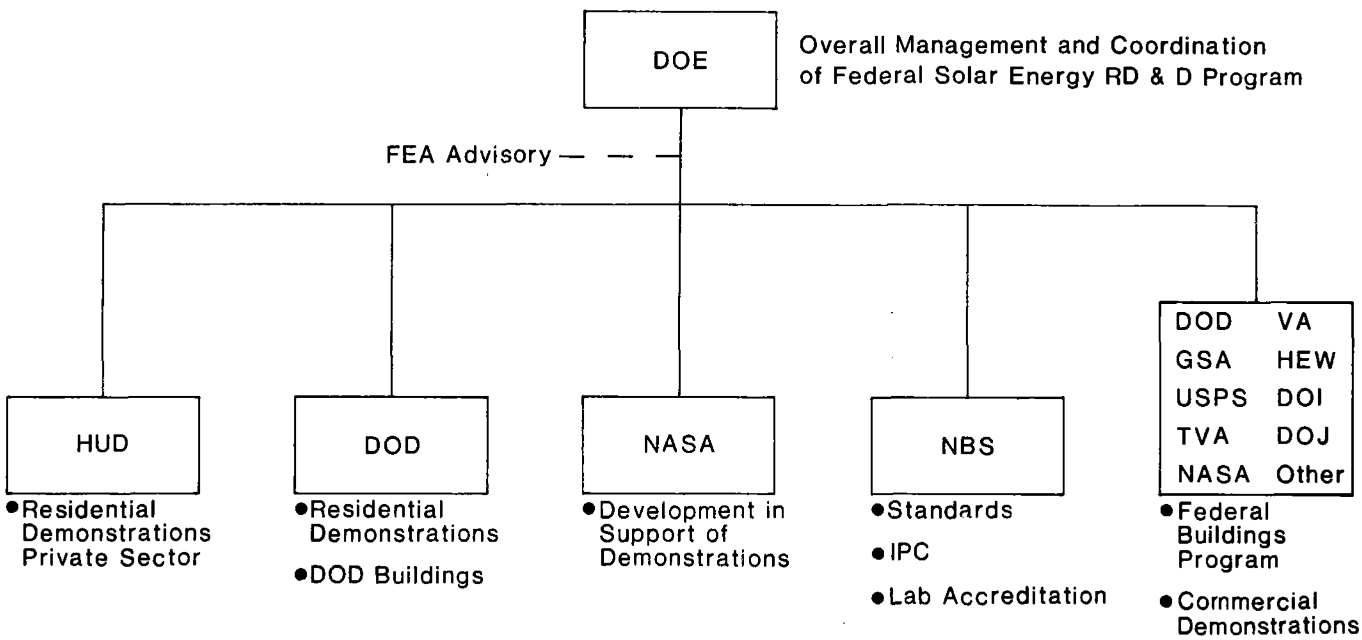
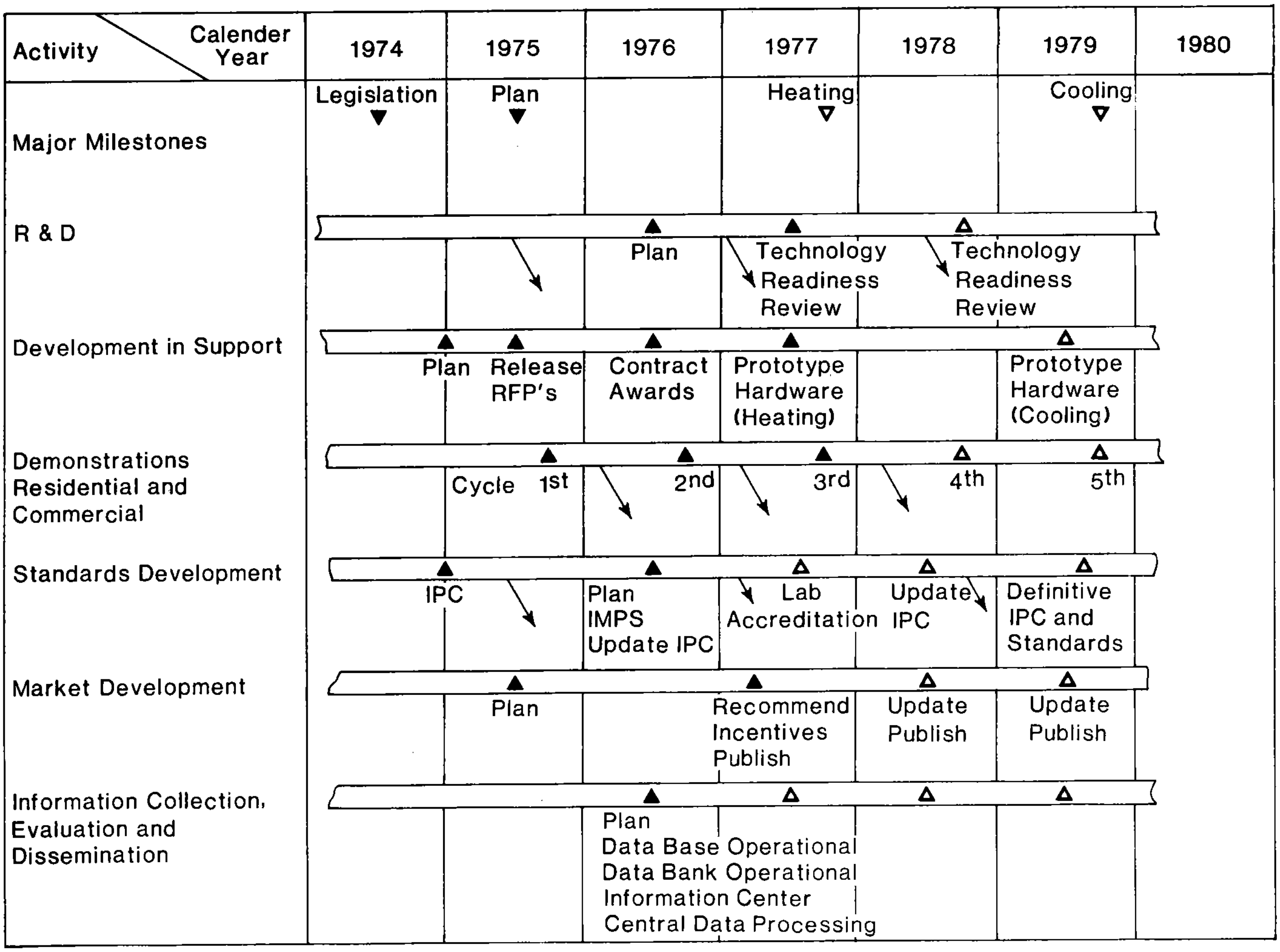


Figure 7-13. FEDERAL SOLAR HEATING AND COOLING PROGRAM



improved collector durability and performance. Systems will be packaged to reduce costs, and a few systems will be evaluated. Higher temperature collectors will be emphasized in order to compensate for the heat-exchange temperature drops elsewhere in the system. Storage tanks and auxiliary heaters will be designed to maximize stratification. The best pattern of collector connection will be determined.

H1: Solar-Assisted Heat Pump

A comprehensive analysis of system sensitivity will be made through computer simulation of attractive configurations. This sensitivity analysis will be carried out for various climatic zones and design parameters. Performance prediction will be done for both currently available and improved-performance heat pumps. In the second phase, a few operating systems will be built to validate the model and to obtain operating experience. Improved-performance heat pumps will be developed, and trade-offs will be studied. The technology base for the required collectors, storage, heat pumps, and other subsystems must be established.

The solar heating and cooling R&D program of the Electric Power Research Institute (EPRI) emphasizes the development of solar-assisted heat pumps for space heating to provide load management flexibility for electric utilities. Cooperation between the EPRI and DOE programs has been established and will be maintained to avoid unnecessary duplication of effort.

H2: Passive and Other Designs

This category includes, but is not restricted to, passive solar heating concepts. Emphasis will be on determining solar gain, heat storage, and heat release characteristics for various system designs. Thermal simulation computer models of these systems will be generated, validated, and used to determine system design parameters and effective geographical ranges. The energy yields that can be expected in each climatic zone will also be determined. Architectural integration and cost-effectiveness are of paramount concern in the evolution of each design, and information dissemination may be more important for this task than for any other.

Table 7-3. R&D PATH DESCRIPTIONS FOR SOLAR HEATING OF BUILDINGS

Application	Designation	Path Description
Hot Water	W1	Liquid-Heating Collectors
	W2	Air-Heating Collectors
Space Heating	H1	Solar-Assisted Heat Pump
	H2	Direct Solar Heating of Space or Structure
	H3	Air-Heating Collectors
	H4	Liquid-Heating Collectors

Table 7-4. RESIDENTIAL & COMMERCIAL DEMONSTRATIONS

	Total	*Operational*
Residential Projects/Units	346/5158	48/553
Commercial	167	20
Total	513/5325	68/573

Table 7-5. HOT WATER INITIATIVE

State	Number of Grants Available	Requests for Applications (8/8/77)
Connecticut	750	3,500
Delaware	150	500
Florida	1,650	7,000
Maryland	950	8,600
Massachusetts	1,375	3,800
New Hampshire	200	700
New Jersey	1,725	7,000
New York	867	7,700
Pennsylvania	2,800	11,000
Rhode Island	250	100
Vermont	150	850
	10,867	50,750

H3: Air Heating Collectors

Emphasis will be placed on bringing air system state-of-the-art up to the level achieved for liquid systems. This can be done through collector development, stressing performance, cost optimization, materials, and testing. In addition, system development will be carried out, stressing design and layout configurations which minimize system costs. Hybrid systems which use direct solar gains also will be extensively investigated.

H4: Liquid Heating Collectors

The vigorous national industry in this area will be supported by collector R&D which stresses materials characterization and development. Installation costs will be reduced by simplifying manifolding, connections, and thermal storage assemblies. Results of numerous system tests will be made available, computer simulation codes will be validated, and simplified methods of system design will be determined and described.

PRINCIPAL DEVELOPMENTS IN FY77

- Over 10 million square feet of solar collectors were sold for space heating and hot water.
- Several quality design methods were published and distributed widely, including the FCHART and SOLOCOST approaches.
- Considerable progress was made on the establishment of standards (Table 7-6).
- The various design techniques and design programs, under the direction of Fred Morse of DOE, were successfully compared.

Table 7-6. STANDARDS & PERFORMANCE CRITERIA DEVELOPMENT

- Residential Interim Performance Criteria (Jan. 1, 1975)
- Commercial Interim Performance Criteria (Feb. 28, 1975; Revised Nov. 1976)
- ASHRAE 93-77, Solar Collector Testing Standard (Adopted Feb. 1977)
- ASHRAE 94-77, Thermal Storage Device Testing Standard (Adopted Feb. 1977)
- Residential Heating, A/C, Solar Installation Standards (SMACCNA, Feb. 1977)
- HUD Intermediate Minimum Property Standards (July 1977)

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

A major problem facing solar energy space heating and hot water systems is installation cost. Despite progress in lowering fabrication and distribution costs, there seems to be no easy way to reduce installation costs, which average about $20/hr. for skilled technicians, and which amount to about $10/sq ft of installed collector. The cost breakdown for solar collectors is currently about $3-4/sq ft for materials; about $3/sq ft for manufacturing profit; $10/sq ft for distribution costs, such as inventory, overhead, and profit to distributors and dealers; and $10/sq ft for installation. Among those with major dissenting views is Amory Lovins,[2] who feels that good collectors can be fabricated at about $1/sq ft. Many, however, disagree with that view and feel that such collectors would not be durable for the 20-year lifetime of houses.

Notes

[1]U.S. Energy Research and Development Administration, *National Program Plan for Solar Heating and Cooling of Buildings*, Annual Progress Report, ERDA 76-6, November 1976.

[2]Amory B. Lovins, *Soft Energy Paths: Toward a Durable Peace*. (San Francisco: Friends of the Earth International, 1977).

8. SOLAR COOLING OF BUILDINGS

BASIC TECHNICAL DESCRIPTION

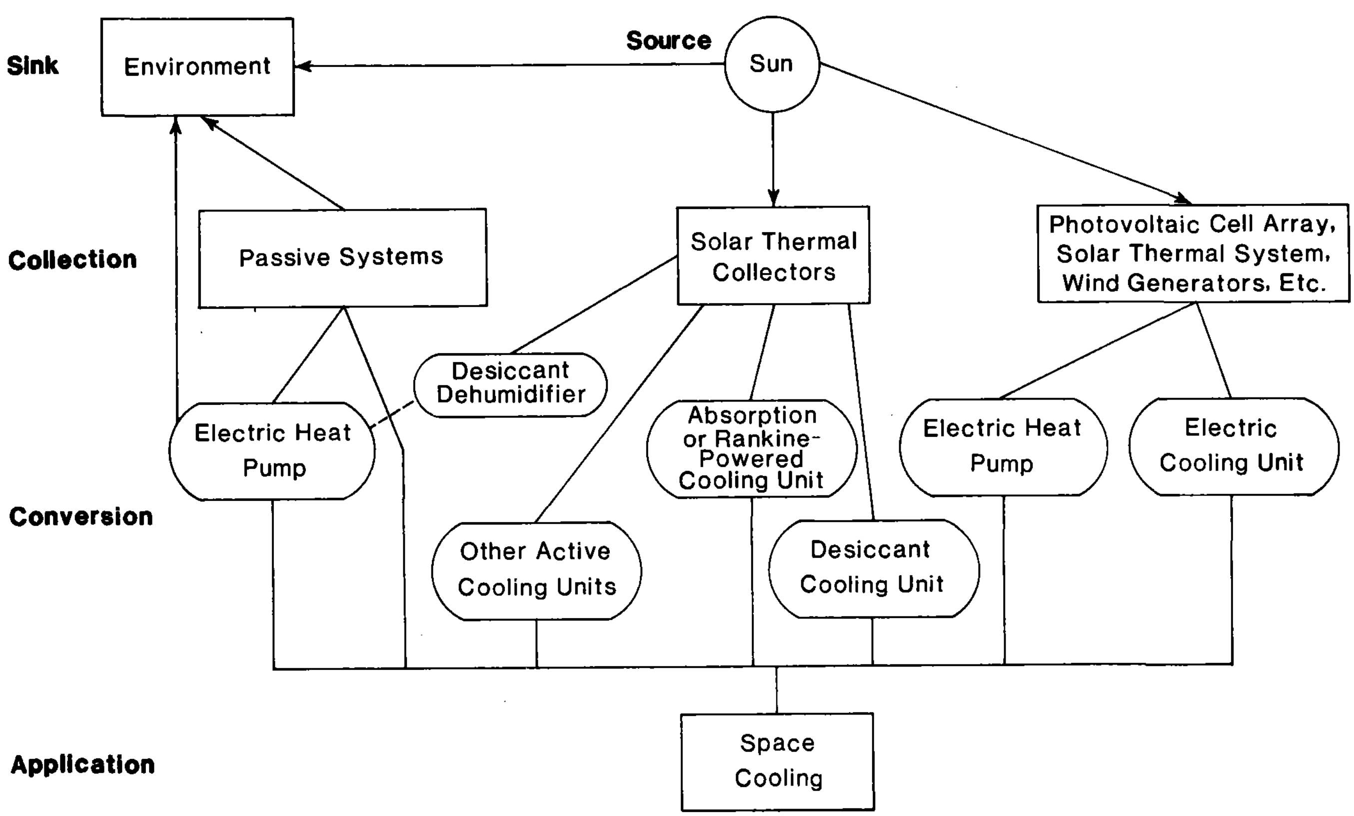
The scope of solar cooling of buildings discussed in this chapter is shown in Figure 8-1. The maturity of the technologies ranges from the existing, mass-produced, vapor compression units, to concepts which are still in the early research phase.

There are three fundamental approaches being pursued for the use of solar energy to cool buildings. The first approach calls for the conversion of incident solar energy into heat, which is then used to drive a thermodynamic cycle for cooling. The second fundamental approach is to convert incident solar energy into electricity, which can then be used to drive an electric heat pump for cooling. The third approach involves passive solar cooling concepts, which are discussed in another section. A combination of these approaches also can be used in hybrid configurations. The following discussion will concentrate on the thermal approach.

Thermal Systems

There are three basic types of thermal systems being pursued in the national program. In each of the three, solar energy promotes a reversible phase change in a refrigeration fluid. The exothermic

Figure 8-1. PATHS TO SOLAR SPACE COOLING



Source: Adapted from ERDA 76-144.

(outgoing heat) portion of the change occurs at high temperature and the endothermic (incoming heat) portion at low temperature. These three basic approaches are:

- heat engine/vapor compression;
- *ab*sorption/desorption processes;
- *ad*sorption/desorption processes.

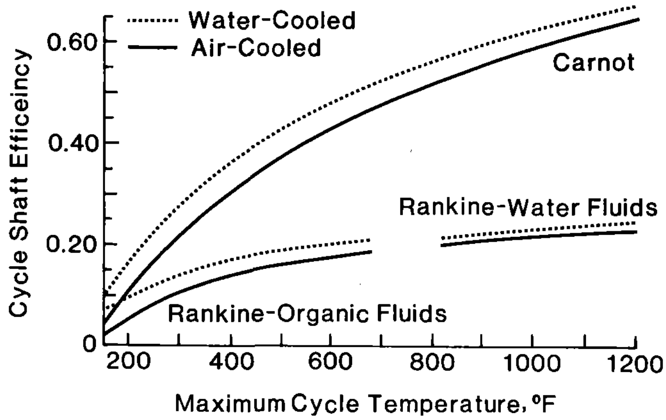
Heat Engine/Vapor Compression

In most refrigeration machines, a refrigerant fluid is vaporized; the heat required for the heat of vaporization is supplied from the cooling load. The refrigerant vapor is then condensed; the heat of condensation which is liberated in the process is rejected to the environment. In a practical machine, work must be done on the refrigerant fluid. In the case of a vapor compression machine, this work is done in the mechanical compression of the refrigerant gas. That is, once the refrigerant liquid has been evaporated (at normal room temperatures) the gas created is compressed so that the condensation occurs at an elevated temperature; the heat is then rejected to a "sink" (the outdoors), which is at a higher temperature than the space being cooled. This is the principle of the refrigeration machine used in most buildings today. In standard equipment, the energy to drive the compressor is electrical.

In the case of a solar-driven cooling system, the refrigerant gas can be mechanically compressed by a solar-powered heat engine. There are many heat engine cycles which could be considered for the compressor in a solar air conditioning system. However, in the temperature range appropriate for solar operation, the Rankine cycle appears to have the best performance. The Rankine cycle is a closed sequence of thermodynamic processes which convert heat into mechanical energy. The conversion is accomplished in a series of cyclic changes in the thermodynamic state of the working fluid. The cycle is initiated by evaporating the working liquid using solar thermal energy. The vapor generated is expanded through a piston, turbine, or rotary vane. This expansion process extracts work from the gas, lowering both its temperature and its pressure. The gas then flows to a condenser, where the heat of condensation is rejected to the heat sink. The process is repeated cyclically to generate the mechanical work required to accomplish the compression in a separate, vapor compression, refrigeration machine. At temperatures appropriate to solar applications, the efficiency of this process is low, as shown in Figure 8-2.

The choice of working fluids in a Rankine cycle heat engine depends primarily on the temperature at which the process is occurring. In conventional utility power plants, where the temperatures are extremely high, the preferred working fluid is water. As the temperature is reduced below 500°, other organic working fluids, such as fluorocarbon refrigerants, are more suitable. The overall performance of a heat engine/vapor compression refrigeration system is the product of the efficiency of the heat engine and the energy efficiency ratio of the vapor compression machine. The latter value is in the range of 3-5 for equipment currently available. Thus, the Coefficient-of-Performance (the cooling effect divided by the heat energy input) is in the range of 0.3 to 0.6 for a Rankine cycle, vapor compression system, operating at flat-plate collector temperatures (approximately 200°F.)

Figure 8-2. CYCLE SHAFT EFFICIENCY VS. MAXIMUM CYCLE TEMPERATURE FOR SMALL RANKINE ENGINES



Source: *National Program Plan for the Solar Cooling of Buildings.* (In Preparation April 1978).

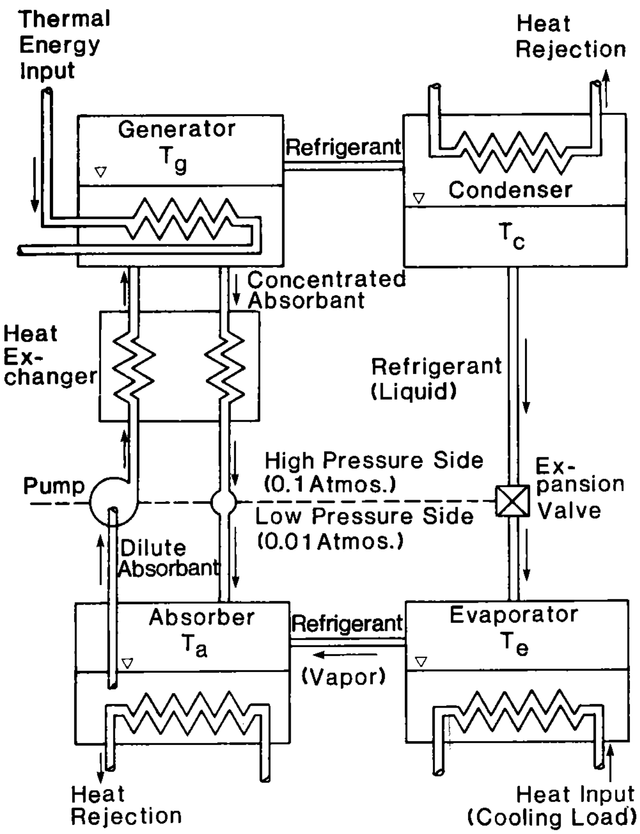
Since the Rankine cycle performance increases markedly with increases in the input temperature, one approach to increasing the operating temperature of the heat engine is to use a fuel super-heat. In this cycle, the energy to evaporate the working fluid is solar energy. The vapor then is boosted to a temperature of 1100°F by combustion of a fossil fuel. Because of the high heat of vaporization, only 25% of the energy needs to be supplied from the fossil energy source and the overall COP of the operating system can be increased by a factor of more than 2. Figure 8-2 compares the performance of the solar and the fuel-assisted heat engines. Other investigators are working with concentrating solar collectors to similarly boost the working fluid temperature.

Absorption Cooling

An alternative to mechanical compression of a refrigerant vapor, as the method for changing the temperature at which the evaporation and condensation of a refrigerant occurs, is the use of the absorption process. This process, which has been known and used in commercial cooling equipment for many years, has been extensively studied, both analytically and experimentally, for application with solar heat.

The absorption process works in an opposite way from vapor compression. In vapor compression, the higher pressure of the condensing vapor increases in the temperature of condensation. In the absorption process, on the other hand, the saturation pressure of the vapor above the absorbent material is reduced below its normal value because of the affinity of the vapor for a concentrated absorbent. This causes a depression in the evaporator temperature and pressure and thus allows heat to be absorbed at a lower temperature (the room temperature).

Figure 8-3. BASIC SINGLE-EFFECT ABSORPTION CYCLE



Source: Adapted from NSF/RANN 76-012, p. V-3.

The process is shown in Figure 8-3, and can be traced through the four basic components shown. Dilute absorbent is concentrated in the generator, driving off water vapor through the input of thermal energy, in this case solar energy. The vapor driven off is condensed to a liquid by rejecting the heat of condensation to the ambient heat sink. This refrigerant liquid is then passed through an expansion valve into the low pressure region of the evaporator where it is evaporated by heat absorbed from the cooling load. The low pressure is maintained because the vapor is absorbed by the concentrated absorbent. The heat of absorption is rejected to the ambient heat sink. The cycle is completed by the return of the dilute absorbent to the generator through a counter-flow heat exchanger, which allows recovery of the sensible heat between the two absorbent streams.

The cycle described uses a single-stage generator. Higher efficiency can be attained, at the expense of greater complexity, by using a two-stage generator. In this arrangement, refrigerant is boiled off the absorbent in two steps; the heat of condensation in the first stage is used to evaporate the refrigerant in the second stage, so essentially twice the vapor can be created. This requires higher temperatures but can increase the efficiency by almost a factor of 2.

Many absorbent-refrigerant pairs are possible. However, research to date has developed only two which are satisfactory for commercial use. They are (1) water and ammonia and (2) lithium bromide and water. The use of the water/ammonia combination has been inhibited in solar applications thus far because of the high temperatures required in the generator and the undesirability of using ammonia refrigerants in building spaces. On the other hand, this combination is particularly suited for air-cooled, heat rejection equipment. Most residential and commercial equipment uses the lithium bromide/water combination, and it has been pursued in most of the solar energy cooling research thus far. The main disadvantage of the use of lithium bromide lies in its solubility vs. temperature characteristic. This equipment typically requires water cooling to prevent the occurrence of crystallization of the salt in the absorber. Research is underway to identify suitable anti-crystallization additives whcih would permit air cooling of the lithium bromide system.

In an absorption generator, once an adequate temperature is reached to promote the required vaporization, increased temperatures are of little benefit to performance. Figure 8-4 compares the performance of a single-stage and a double-stage lithium bromide air conditioner, and the Rankine heat engine.

Figure 8-4. COEFFICIENT OF PERFORMANCE COMPARISON FOR WATER-COOLED RANKINE ENGINE/VAPOR COMPRESSION COOLING UNITS AND ABSORPTION COOLING UNITS

Rankine Engine/Vapor Compression Working Fluid:

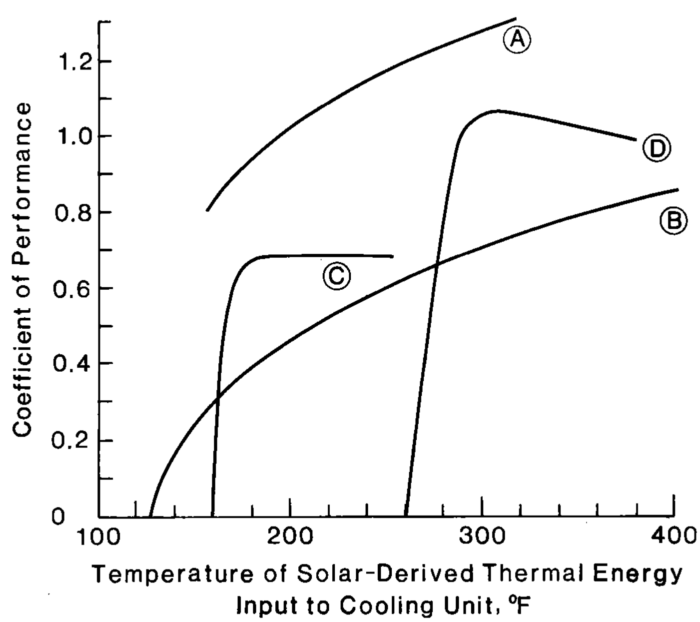
(A) Water (Superheat = 1100°F)

(B) Organic Fluid

Lithium Bromide/Water:

(C) Single-Stage Absorption

(D) Two- Stage Absorption



Source: *National Program Plan for the Solar Cooling of Buildings*.

Adsorption Cooling

Adsorption is closely related to absorption. However, no physical or chemical changes occur during adsorption. Rather, the process depends on van der Waals and capillary forces to bind the adsorbate to the surface of the adsorbent. The effect, however, is the same as in the absorption process: the vapor pressure of the refrigerant vapor above the adsorbent bed is reduced. The surface forces which bind the water vapor on the adsorbent in liquid form cause a reduced vapor pressure of refrigerant above them. The chief advantage of the adsorption process is that the inert adsorbent permits an open-cycle or desiccant process; the working fluid is the building air being cooled. In the desiccant cycle, the building air is dehumidified by passage through a desiccant bed. The dry air then can be evaporatively cooled. The desiccant bed is regenerated by heating it with solar thermal energy, also in open-cycle fashion.

Desiccant systems have been experimentally demonstrated and have been shown analytically to have the potential for good performance when operated from a solar source. COP's in the range of 0.6 to 0.8 have been predicted.

Solar Electric Cooling Systems

An alternative to the thermal systems is a concept that would replace the thermal collectors with a photovoltaic panel or other solar electricity system. This panel would generate DC electricity at a conversion efficiency typically of 10%-15%. The electrical power thus derived could be used to drive the commercial vapor compression machine described above. In the case where such a machine has an energy efficiency ratio of 5, the overall COP of the process would thus be 0.75. In a total-energy variation of this concept, the 85%-90% of the incident energy which is not converted to electricity would be available as a heat source for a complementary thermal process. The major issue in this approach, of course, is the cost of the solar electric system.

The heat pump is also the subject of a substantial research effort. The heat pump is physically the same equipment as a vapor compression air conditioner; the term "heat pump" implies the use of the equipment for both heating and cooling applications. The heating mode in a heat pump is accomplished by a wintertime rearrangement of the refrigerant flow through the system so that the cycle heat rejection is into, rather than out of, the building space. Heat pumps are commercially available and have a substantial history of application in both industrial and residential situations. There are two operating modes of the heat pump, however, which are unique in the solar system application. In one application, the heat pump is used in conjunction with the solar heating system so the heat source is air or liquid which has been heated by a solar collector. The performance of the heat pump can be substantially improved by increasing the temperature of the heat source. However, the heat pump must be redesigned specifically for the higher temperature source.

With a solar collector it is possible to project a heating season COP in the range of 3 to 4, rather than 1.5 to 2 using ambient air as the heat source.

A second configuration of heat pump use is in an annual cycle of energy storage for heating and cooling. In the heating season, a large reservoir is used as a heat source at higher temperature than ambient; this allows high performance of the equipment in the heating mode. In the cooling season, the reservoir (by then a block of ice) is a heat sink for a vapor compression air conditioner. Work for optimizing heat pumps in both of these operating modes is underway.

FEDERAL PROGRAM GOALS

The potential markets for solar cooling equipment are determined by:

- rate of projected new construction in both residential and nonresidential areas;
- ratio of incident sunshine to cooling demand;
- rate of economic growth in the specific geographic area;
- cost of competing energy sources;
- cost of the solar energy equipment.

When industry projections are examined through the year 1990, it appears that much of the air conditioning market will occur in applications and in geographic locations specifically conducive to the use of solar air conditioning. The Solar Energy Industries Association has developed projections on the displacement of fossil energy by solar cooling systems. These projections have been adapted as the goal for the Federal cooling program shown in Table 8-1. In the residential market, a 4% penetration of new air conditioning installations is projected by the year 1990, which represents 77,000 units per year. At three tons per unit, this amounts to nearly 250,000 tons of air conditioning per year.

The commercial market penetration is projected at 8%. Since there is such great variability in the size of each installation, the capacity is identified as 450,000 tons per year by 1990. The total installed air conditioning capacity in the 1980s is 54 million tons. The cumulative amount of oil displaced in the course of the program amounts to 30 million barrels. Quite obviously, these figures are sensitive to the market penetration percentage, which is a strong function both of the cost for which the installations can be sold and of the level of Federal subsidy (present funding levels for the National Cooling Program are shown in Table 8-2). The projections shown in the SEIA Report reflect a conservative estimate of the cost for cooling systems in the 1980s. If improvements can be made in reducing the cost to levels in the range of $1,000 to $2,000 per ton, the penetration of the market could be greater.

PRINCIPAL DEVELOPMENTS IN FY77

- Rankine cycle design was completed for equipment having 3, 10, 25, and 75 ton cooling capacity.
- Three ton, Rankine cycle model was tested.

Table 8-1. ANNUAL GOALS FOR INSTALLATION AND ENERGY RESOURCE DISPLACEMENT

National Program Plan for Solar Cooling of Buildings

	1985	1986	1987	1988	1989	1990
RESIDENTIAL BUILDINGS						
INSTALLATIONS (1000 dwelling units-year)						
Without National Program Plan	0.6	1	2	5	11	22
With National Program Plan	6	11	20	33	55	77
PERCENT OF COOLING MARKET						
Without National Program Plan	<0.1	<0.1	0.1	0.3	0.5	1
With National Program Plan	0.3	0.5	1	2	3	4
OIL DISPLACED* (1000 bbl./year)						
Without National Program Plan	20	40	85	180	400	800
With National Program Plan	150	350	700	1300	2400	4000
COMMERCIAL BUILDINGS						
INSTALLATIONS (1000 tons/year)						
Without National Program Plan	5	9	16	30	55	110
With National Program Plan	13	35	70	130	250	450
PERCENT OF COOLING MARKET						
Without National Program Plan	0.1	0.2	0.3	0.5	1	2
With National Program Plan	0.2	0.6	1	2	4	8
OIL DISPLACED** (100 bbl/year)						
Without National Program Plan	90	180	350	700	1300	2600
With National Program Plan	200	550	1300	2700	5500	11000

Note: Energy resource displacement basis is barrels of oil equivalent of primary energy.
*Solar cooling systems and solar heating and cooling systems.
**Solar cooling systems.

Source: *National Program Plan for the Solar Cooling of Buildings.*

Table 8-2. NATIONAL COOLING PROGRAM—FY78 BUDGET

R&D Budget	$2.6 Million
Development Budget	$4.8 Million
Total	$7.4 Million

Source: *National Program Plan for the Solar Cooling of Buildings.*

- Development was initiated of evaporatively cooled absorption equipment of unitary design.
- Advanced R&D was initiated on
  * desiccant systems;
  * Rankine systems;
  * absorption systems.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Several of the cooling approaches have size and geographic constraints which limit the potential application. The active systems are generally applicable to the full range of applications without geographic restriction. However, passive cooling is generally limited to small sizes and to the arid climate of the Southwest. It appears that desiccant systems, which fall under the definition of active, probably will be most cost-effective in applications requiring a large ventilation load.

In none of the approaches is it economically feasible to provide all the cooling load using the solar equipment; therefore, an important problem is how the auxiliary cooling can be interfaced with the solar unit. A further problem relates to the parasitic power required to support such equipment as pumps, fans, and controls.

9. PASSIVE SOLAR DESIGN

BASIC TECHNICAL DESCRIPTION

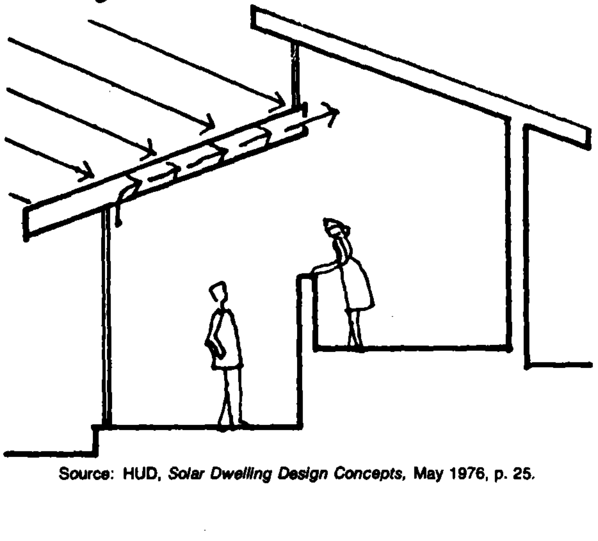
Passive solar design refers to architectural features, components, and/or assemblies which make use of the natural transfer of thermal energy (involving conduction, convection, radiation, and vaporization) for the purposes of hot water heating and space conditioning. Thermal energy transfer into and out of storage, and around and through conditioned space, is also by natural means. Control elements and other comfort regulating devices are not necessarily components of passive systems. Advantages of passive solar systems over conventional systems are cost-effectiveness, labor intensity, durability, retrofit potential, and decentralization.

Five generic passive solar design categories are the following:

Thermosyphoning Walls, Roofs, Collectors

Heated air becomes lighter and moves upward while cooler air replaces it. This concept, thermosyphoning (Figure 9-1), can be employed to circulate natural heat which collects in the air spaces of walls, collectors, and roofs. Some of the more significant work in this area is being done at the Centre Nationale de la Recherche Scientifique (CNRS) in Odeillo, France, under the direction of Professor Felix Trombe, and at Los Alamos Scientific Laboratory by Doug Balcomb and associates.

Figure 9-1. THERMOSYPHONING ROOF

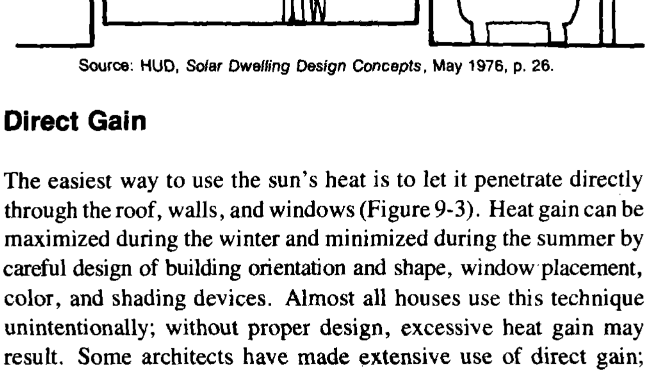


Source: HUD, *Solar Dwelling Design Concepts*, May 1976, p. 25.

Roof Ponds

Bagged water incorporated into roof design (Figure 9-2) will collect and store both solar heat and nocturnal coolness. The rate of thermal energy collection and release is controllable through the use of movable insulating panels. In 1973, Harold Hay built a house at Atascadero, Calif., incorporating roof ponds which provide 100% of heating and cooling needs. Other roof pond structures are being constructed with funding provided by HUD grants.

Figure 9-2. PATENTED SOLAR POND CONCEPT USED IN ATASCADERO HOUSE



Source: HUD, *Solar Dwelling Design Concepts*, May 1976, p. 26.

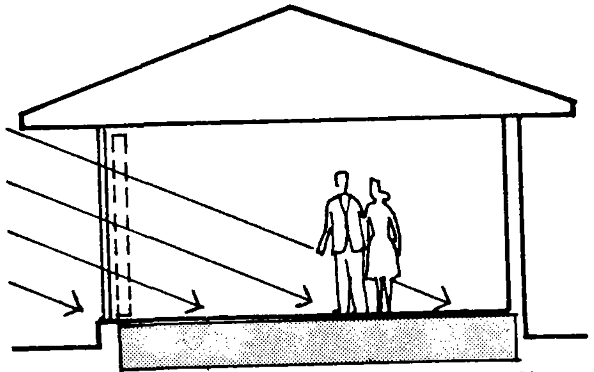
Direct Gain

The easiest way to use the sun's heat is to let it penetrate directly through the roof, walls, and windows (Figure 9-3). Heat gain can be maximized during the winter and minimized during the summer by careful design of building orientation and shape, window placement, color, and shading devices. Almost all houses use this technique unintentionally; without proper design, excessive heat gain may result. Some architects have made extensive use of direct gain; especially David Wright, Bruce Anderson, and Malcolm Wells.

Concrete and Water Wall Collectors

The concrete wall, or Trombe wall, concept uses a high thermal mass wall which is generally painted a dark color and sometimes glazed. Solar energy absorbed by the dark surface is stored in the thermal mass and later is reradiated into the building's interior.

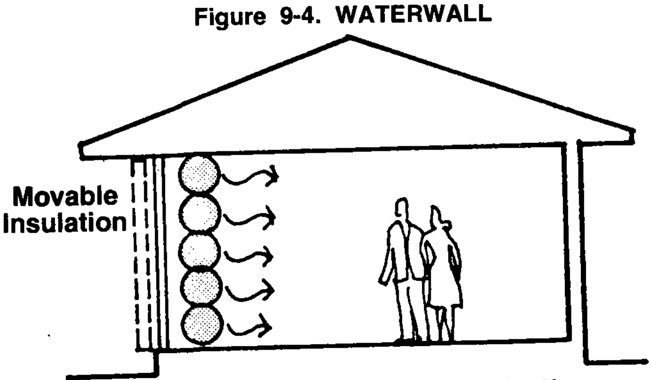
Figure 9-3. DIRECT GAIN BY SOUTH-FACING WINDOW



Source: HUD, *Solar Dwelling Design Concepts*, May 1976, p. 24.

(The mass material and its volume determine the reradiation time lag.) The water wall (Figure 9-4) is a variant of this concept, using bagged water in the hollow of concrete blocks which compose the wall. Alternatively, containers of water can be directly exposed to solar radiation by placement next to windows. Steve Baer pioneered the water wall technique, incorporating movable insulation to reflect radiation onto barrels of water in the daytime. At night, the reflectors become insulating panels.

Figure 9-4. WATERWALL

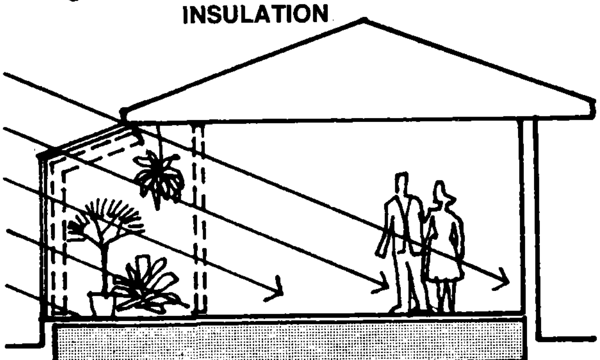


Source: HUD, *Solar Dwelling Design Concepts*, May 1976, p. 28

Greenhouses

The greenhouse (Figure 9-5) is an energy and food producing structure which can be easily attached to the south side of existing buildings. The addition of a greenhouse or its incorporation into new construction increases the solar collection area, but with a corresponding increase in heat loss if the exterior surface is not insulated at night.

Figure 9-5. GREENHOUSE WITH MOVABLE INSULATION



Source: HUD, *Solar Dwelling Design Concepts*, May 1976, p. 25.

DESCRIPTION OF FEDERAL PROGRAM

Providing assistance to industry for the development and early introduction of economically competitive, environmentally acceptable, and operationally safe passive systems is the principal goal of the DOE Passive Solar Heating and Cooling Program. In 1977 and 1978, the DOE program (funded at a total of $2.8 million for both years) concentrated on R&D with some low-level effort in information dissemination. That emphasis was redirected, however, as a result of a November 1977 program planning workshop. Attended by about 70 principals in the passive field (including architects, builders, academia, government contractors, and government planners), the workshop concluded with a working consensus that the major constraints to passive deployment are educational and institutional rather than technical.

Priority FY79 tasks, geared toward passive commercialization include:[1]

- documentation of passive systems performance and cost;
- development and operation of a passive solar information system;
- development of passive design guidelines;
- demonstration of passive solar in new and existing residential and commercial buildings;
- promotion of passive applications in Federal buildings;
- identification of the necessary legislation, codes, and incentives to mitigate or eliminate existing legal or institutional constraints to the use of passive solar design.

Companion tasks in the area of passive R&D include:[2]

- an analysis of existing materials for use in passive system construction as well as the development of new materials;
- development of cost-effective, mass-producible, and easily installable passive assemblies;
- development of computer simulation models of passive solar systems;
- controlled, full-scale testing of passive systems in different climates.

Though FY79 funding levels for DOE's passive program have not yet been established, in March 1978, the House Committee on Science and Technology recommended a total budget of $16 million, with $8 million for R&D and $8 million for the demonstrations (including $3 million each for residential and commercial demonstrations, and $1 million for standards development).

PRINCIPAL DEVELOPMENTS IN FY77

In 1977, Los Alamos National Laboratory constructed 14 passive test rooms and accumulated one year of data for various thermal storage wall configurations. In addition the Laboratory monitored 10 passive buildings in New Mexico; Sandia Laboratories published partial results of the instrumentation.[3]

In November 1977, DOE sponsored a passive program planning workshop in Reston, Virginia. Attendees assisted DOE planners in developing a strategy to hasten the widespread use of passive solar design.

Approximately 1000 people participated in the Second National Passive Solar Energy Conference held in March 1978 in Philadelphia. Speakers presented a wide range of technical and nontechnical papers.

Preparation of the first national passive program plan began subsequent to the Reston planning workshop. The final plan, expected in late 1978, will include passive definitions, a description of the overall planning context, and identification of needed commercialization tasks and long-term R&D tasks.

HUD began planning a residential passive design competition and demonstration. Requests for proposals should take place by summer 1978.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Most of the problems associated with passive solar design are nontechnical and noneconomic in nature. At the November 1977 DOE planning workshop, major problems were categorized and defined as follows:

Social

- lack of credibility;
- low visibility and accessibility;
- misconceptions about comfort levels in passive buildings;
- hardware mentality in all sectors.

Education/Technology Diffusion

- lack of basic consumer understanding of energy and economics;
- neglect of passive solar design in academic curricula;
- scarcity of skilled professionals with understanding of passive techniques.

Institutional

- no organized constituency;
- lack of passive infrastructure within building industry;
- conservative nature of banking/financing sector;
- conservative and decentralized nature of building industry;
- labor union jurisdiction.

Government (all levels)

- Federal subsidies to conventional fuels;
- insufficient funding for demonstrations, monitoring, education, technology transfer, and studies on incentives, economics, and policy options;
- antiquated building codes and a maze of regulations

Legal

- siting and sun rights issues;
- lack of accepted definition of passive, and therefore possibly no inclusion in Federal tax credits.

Technical

- complexity and uncertainty of some thermal loss/gain calculations;
- lack of mass production techniques.

Economics

- financing is the aspect of economics to be dealt with most seriously; other aspects of economics not considered a barrier.

Notes

[1]Department of Energy, "Natonal Program Plan for Passive Solar Heating and Cooling," Draft Planning Report, February 1978, pp. 8-9.

[2]Ibid., p. 16.

[3]*Solar Energy Intelligence Report*, 20 March 1978, p. 76.

10. AGRICULTURAL AND INDUSTRIAL PROCESS HEAT APPLICATIONS

AGRICULTURAL APPLICATIONS

Basic Technical Description

Historically, agricultural applications of the sun's heat were widespread. The use of natural sources of energy was universal in the agricultural economy of pre-industrial society. The age of industrialization and industrial fuels not only reduced the scope and area of agricultural employment, but also changed the nature of farming processes and their requirements for energy. Industrial fossil fuels, because they were both convenient and abundant, were soon substituted for "natural" forms of power such as animal work, wind and solar heat. The energy intensity of agriculture became greater as new processes were employed directly on the farm and even more dramatic increases in energy use followed the development of chemical fertilizers and pesticides. The sun still supplies large amounts of energy for photosynthesis and for the natural circulation of air and water. But the direct use of solar thermal energy has diminished in relative importance to United States agriculture because of the substitution of fossil fuels.

Energy used in American agriculture amounts to nearly 3% of the total energy consumed in the United States annually, though only about 2% is energy used directly on farms (1.3 Quads in 1974). The remaining 1% is energy invested as feedstock and production energy of agricultural chemicals such as fertilizers, feeds and pesticides. It is also estimated that another 13% of United States energy consumption is used in the processing, distribution and preparation of food.[1] Although certain food processing projects are included in the agricultural applications solar program, emphasis of the program has been on the direct use of energy on farms. Food processing in plants which are removed from the farmsite is termed an industrial use.

Applications of solar thermal energy in agriculture can be divided into two major areas: irrigation and heating.

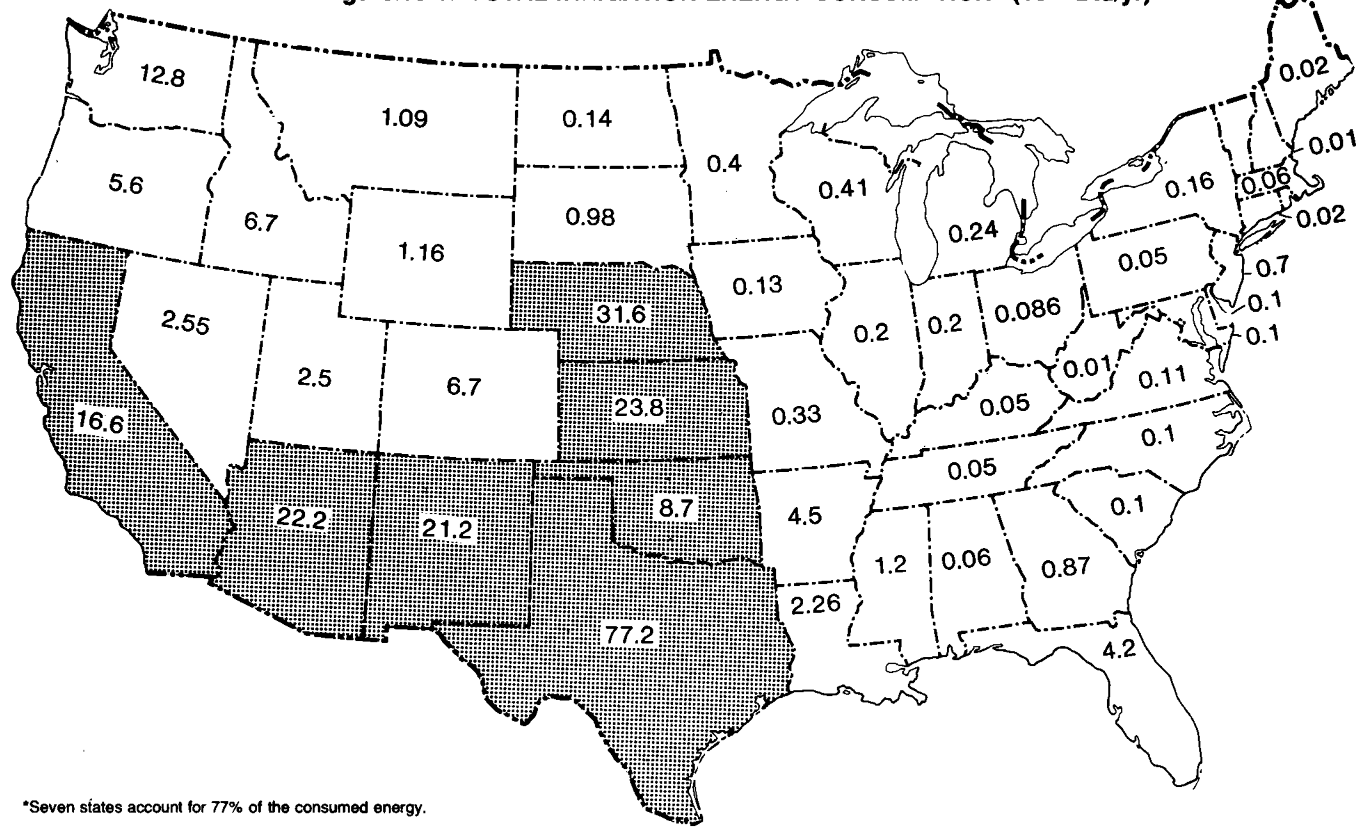
IRRIGATION

Approximately 20% of the direct energy used in the agricultural sector is consumed in irrigation pumping for crop production (260 trillion Btu's annually). The distribution of pumping energy requirements is heavily weighted toward seven southwestern and midwestern states which together account for over 77% of the total irrigation power consumption in the United States today (See Figure 10-1.)[2] The use of solar energy to fulfill these requirements is promising for a number of reasons. First, the concentration of uses is in a climatological area with abundant insolation. Second, irrigation power requirements are predominately confined to the range of 20 to 300 kW per station; this can be supplied by moderate-sized fields of currently available concentrating collectors and organic vapor-cycle engines. Third, in most cases, the seasonal peak in demand for irrigation will correspond to seasonal peaks in insolation. Although daily thermal storage may be chosen, irrigation schedules could be adjusted to preferable daytime pumping schedules, or pumped water storage could be used effectively to reduce system costs associated with storage.

The seasonal nature of irrigation pumping requirements may also be taken advantage of by designing multiple-use systems which use heat collected from the collector field to provide heat for drying or auxiliary electric power, or shelter/greenhouse heating during nonirrigating seasons.

The use of solar energy for water pumping has a distinguished history; some of the most elaborate solar systems built in early years of solar energy development were designed for the application. The very earliest designs were for integral collection and displacement pumping devices like those of Deliancourt in Algeria and of Mouchot in France in 1860. However, it soon became apparent that solar heat could drive a separate heat engine (such as a steam engine) to power a pump. Mouchot designed such a device in 1878 and exhibited it at the Grand Exhibition in Paris that year. Very large systems of this sort became more appealing as large areas of the arid southwestern U.S. became settled, requiring large amounts of agricultural water pumping. A.G. Eneas and the Solar Motor Company of Boston distributed a concentrator-steam engine system capable of delivering 1400 gallons per minute in 1901. The experiments of Shuman led to installation of a 40 kW system in Meadi, Egypt in 1912, which strongly resembles some of the latest systems installed in the 1970s under ERDA and DOE. Between 1920 and 1973, little was done in solar irrigation applications in this country. A few experiments with ethyl chloride engines to drive irrigation pumps were conducted in Italy in the 1920s and a large, multi-use

Figure.10-1. TOTAL IRRIGATION ENERGY CONSUMPTION* (10^{12} Btu/yr)



*Seven states account for 77% of the consumed energy.

Source: FEA/D-76/459, September 1976.

irrigation solar system was built in the 1950s in Uzbekistan, U.S.S.R.[3]

Current irrigation systems employ a two-loop system to drive Rankine-cycle turbines for pumping power. Water under pressure or organic fluid is circulated in a collector field of concentrating collectors and heated to 300°F or more. The hot fluid flows through a heat exchanger to vaporize a working fluid, such as Freon, ammonia, or ethyl chloride, which then expands through a specially designed turbine to provide shaft power. The fluid is normally passed through a regenerator and a condenser after exiting the turbine, and then is returned to the heat exchanger. Storage may be added in the primary (collector field) loop if desired.

Proposals recently have been made for a one-loop system which heats the working turbine fluid directly in the collector, eliminating the need for an exchanger. Such systems, however, may present problems in the handling of low-vapor pressure fluids in collector receivers.[4]

AGRICULTURAL HEATING

Solar energy may be collected in on-site systems and delivered as direct heat to various agricultural production processes or as space heat for agricultural shelters. Approximately 10% of agriculture's total energy demand can be attributed to on-site demand for heat. The demand areas selected for development by the DOE/USDA program in agricultural process heat account for about 7.5% of the total agricultural energy demand. The areas selected for solar system development, and the 1974 energy demand and primary fuel for each, are listed in Table 10-1.

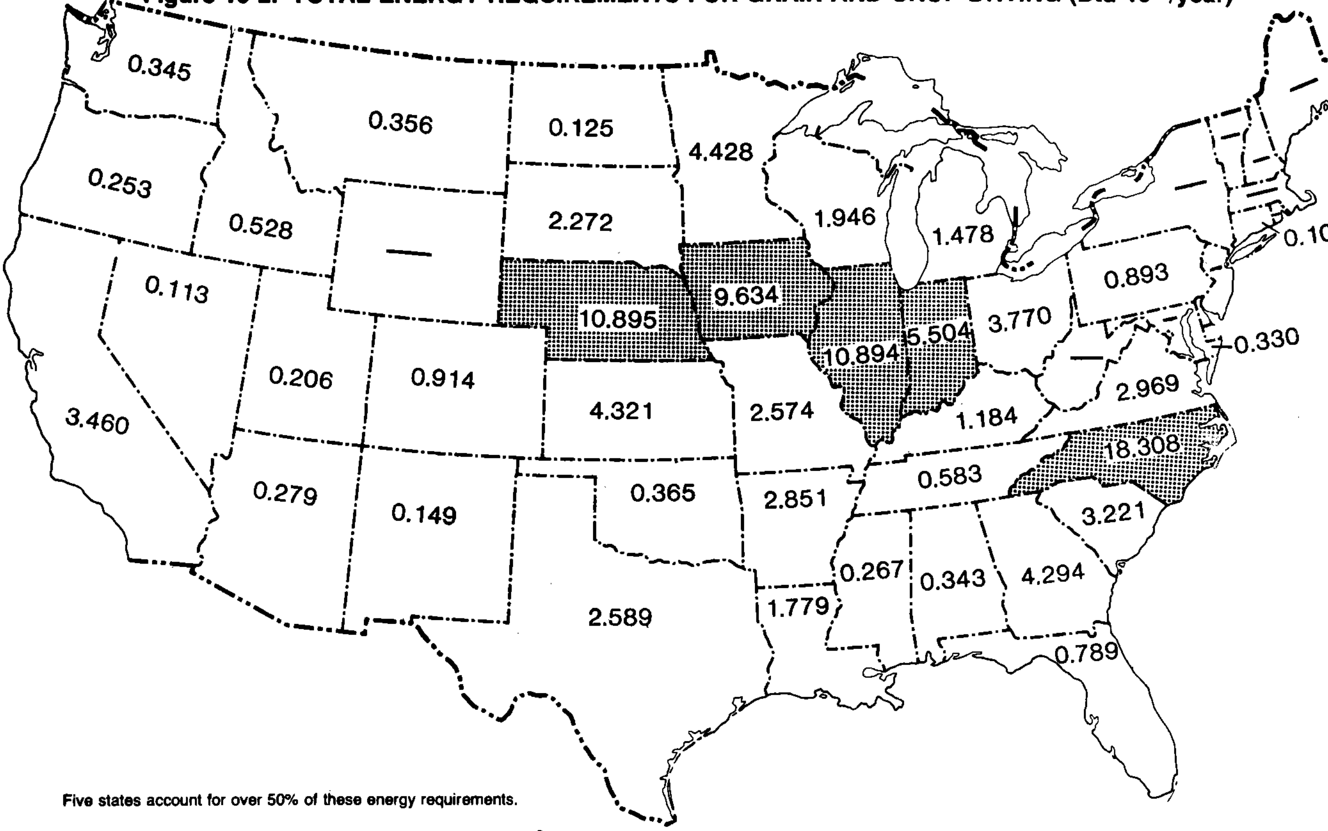
Table 10-1. 1974 ENERGY DEMAND AND PRIMARY FUELS FOR SELECTED AREAS OF AGRICULTURAL HEATING

Operation	1974 Energy Use (10^{12} Btu)	Primary Fuel Used
Grain and Crop Drying	105.3	LPG
Livestock Shelter Heating & Brooding	30.1	LPG
Greenhouse Heating	35.0	Natural gas
On-Site Food Processing	Unknown	Unknown

Source: FEA/D-76/459. September 1976.

The national distribution of these energy requirements is shown in Figures 10-2 and 10-3.

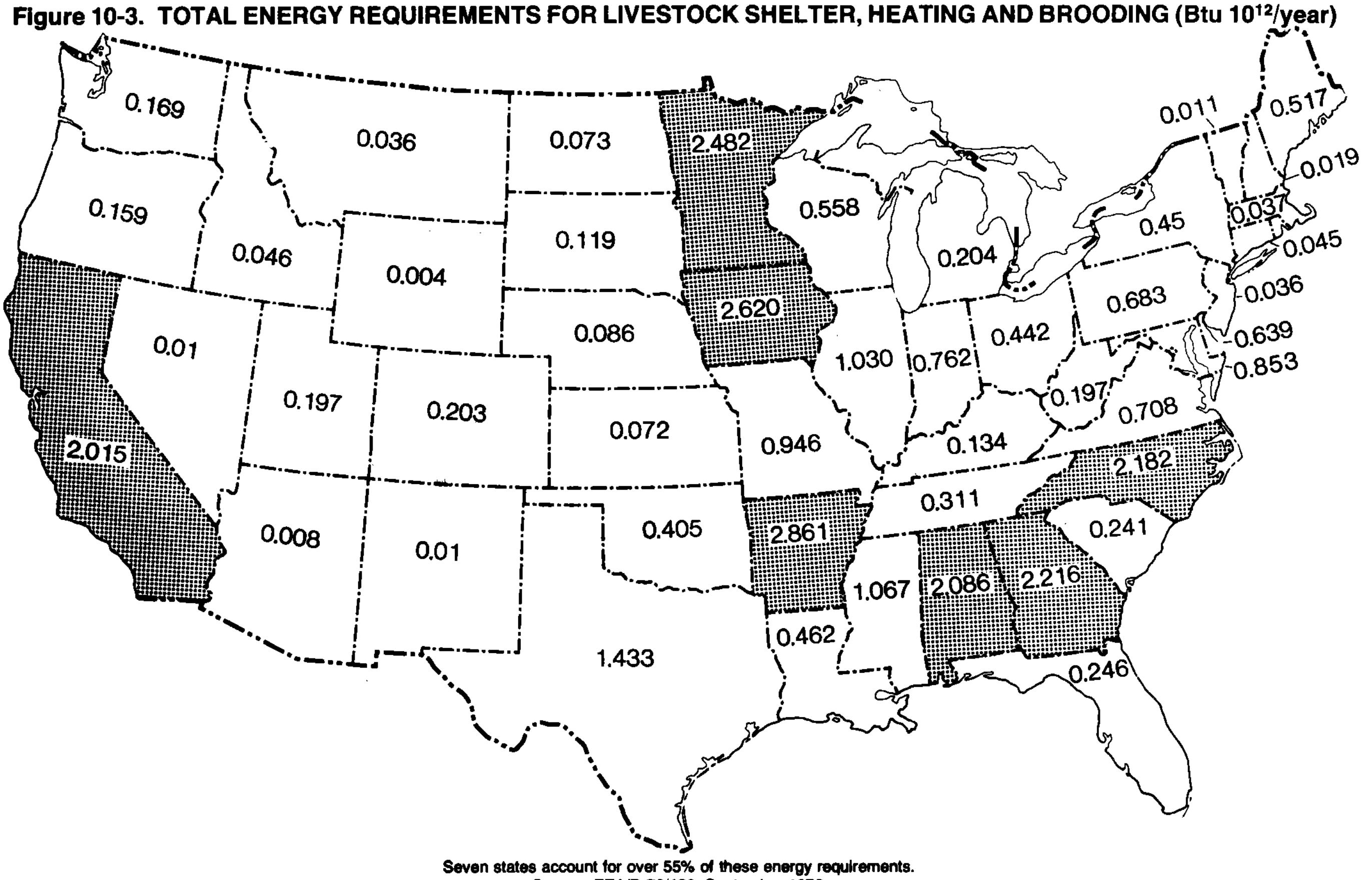
Figure 10-2. TOTAL ENERGY REQUIREMENTS FOR GRAIN AND CROP DRYING (Btu 10^{12}/year)



Five states account for over 50% of these energy requirements.

Source: FEA/D-76/459, September 1976.

Figure 10-3. TOTAL ENERGY REQUIREMENTS FOR LIVESTOCK SHELTER, HEATING AND BROODING (Btu 10^{12}/year)



Seven states account for over 55% of these energy requirements.
Source: FEA/D-76/459, September 1976.

Drying of agricultural products falls into two broad categories. In the midwestern areas of the United States, harvested grains must be dried soon after harvest to allow long-term storage. Grains typically dried on-site include corn, wheat, rice, oats, barley, sorghum, millet, rye, and hops. Although the energy requirements on a national scale are small, dried grain represents the single largest value United States export item. Most research has concentrated on the use of solar collectors (including various forms of flat-plate air collectors, low-cost plastic film collectors, integral building wall collectors and solar ponds) to provide low-temperature air, typically 3-6°F above ambient, to conventional drying bins. Natural air has been extensively used for drying by circulation in upright storage bins or in storage rooms where grain is spread. The emphasis in solar augmentation has been on reducing the drying time required by introducing low-level heat; large air flows are still required. Research is also proceeding into low-temperature collectors to assist heat pumps and high-temperature concentrating collectors/ dryers for significantly reduced drying time. Desiccants such as silica-gel or overdried grain may be used to reduce the humidity of air entering the drying bin.

Very large energy requirements for the curing of products like tobacco, peanuts, and forage, are found in the southeastern and mid-Atlantic regions. As in grain drying, flat-plate or plastic film collectors may be used to provide low-temperature air to drying rooms. In addition, crops such as tobacco may be dried in "greenhouse-type" rooms to make use of passive techniques such as optimal field drying. Research in these areas simply serves to quantify principles which have been used by farmers for years. Stem drying of tobacco and the drying of alfalfa require higher temperatures—the use of concentrating collectors or heat pumps may be necessary.

Livestock shelter heating and brooding facility heating requirements are concentrated in two major areas of the country. Poultry and swine farms have large heating demands in the Southeast, while dairy farm requirements for heating and hot water are significant in the upper Midwest. The technology associated with residential heating and hot water, including the use of the flat-plate air or water collectors, may be applied directly to livestock uses. In many cases, the range of environmental temperatures tolerated by livestock may be greater than for humans, leading to systems of smaller required size, of less cost, or requiring less back-up. Dairy operations require considerable amounts of hot water in addition to space heat. Flat-plate collectors using water or a working fluid might supply both needs. In addition to conventional collector systems, designs have been proposed which use building walls (as in swine farrowing houses) to heat or preheat ventilating air by circulating air in the wall cavity.

Greenhouse heating always has been a solar function. In certain climates, greenhouses may require supplemental heating and/or cooling beyond the intrinsic collecting capacity of the structure. Enhanced solar energy use in greenhouses may be accomplished by:

- improved design of greenhouse buildings, including the integration collectors in the structure, integral storage systems (such as slab floors), and less expensive construction (such as the use of plastic films);
- supplemental air or water heating, using various forms of detached flat-plate or shallow solar pond collector;
- supplemental cooling, using solar energized absorption refrigeration of deep-mine air ventilation.

Certain advantages may also accrue from the combined heating of greenhouses and nearby homes. Heated air may be drawn directly from an adjacent greenhouse into the home during periods of greenhouse overheating when the home requires heat. Alternatively, it may be more cost-effective to heat both home and greenhouse with the same detached solar collecting system rather than separately heating either structure.

Most food processing requirements beyond grain, crop and fruit drying are confined to the industrial sector in the United States. Solar technologies in this area would be similar to those for industrial process heat.

WATER DISTILLATION

An additional area of solar thermal applications to agriculture deserves mention, though this application sees little use in the United States. The use of solar heat to distill and purify water (particularly to disalinate) was first used on a large scale in Las Salinas, Chile, by Wilson in 1872. His system consisted of 64 shallow troughs with sloping clear glazings. Vapor from sea water heated in the troughs would condense on the glazing and flow to a collection tank in which nearly 6,000 gallons of fresh water were collected daily. The principles employed in solar distillation are the same today, and solar distillation "plants" are used on a small scale in isolated areas of Australia, and in small villages in the Mediterranean basin and the Caribbean.[5]

Water distillation systems may be classified in two ways. "Single-effect" systems require an energy input exactly equal to that required to vaporize water; they provide no recovery of the heat released by condensation. "Multiple-effect" systems recover some portion of the heat of condensation. The simple single-effect still, having a clear sloping window over a shallow saline trough, may have an efficiency of 40% and a water yield of $^1/_{10}$ gallon per square foot per day. A multiple-effect system designed by Hodges (Universiy of Arizona) for Sonora, Mexico, delivered 5000 gallons a day with the use of 10,400 square feet of simple collector.[6]

Federal Program Goals

Agricultural applications of solar thermal energy have been developed in two major programs—irrigation and process heat—and reflect the goals instituted in these programs. Goals of applications to irrigation are to:

- demonstrate the feasibility of distributed concentrating collector systems, using state-of-the-art components, to provide power to pumps rated up to 300 kW at competitive energy costs;
- encourage via demonstration the commercial manufacture and installation of such systems;

- define system and component development requirements for continued commercial adoption of solar thermal irrigation;

- define incentives and barriers to widespread adoption, and formulate plans to enhance the market penetration of solar systems.

For applications to agricultural heating the goals are to:

- encourage the adoption of near-term solar technology which can provide substantial heat input to grain drying, crop curing, on-site food processing, and heating and/or cooling of livestock shelters and greenhouses, by demonstrating the technical and economic advantages of available equipment and systems;

- stimulate further research and development of promising components and system designs, and identify performance and climatological data necessary to system design, and demonstration program;

- insure the ability of industry to provide and maintain acceptable levels of cost, reliability, and availability of agricultural heating systems;

- promote the adoption of incentives which will stimulate the conversion from fossil fuels to solar heat;

- identify existing or potential applications for agricultural heating, including multiple uses of solar energy on farms.

Description of Federal Programs

The program developed by DOE has been concentrating on a demonstration of the feasibility of solar thermal energy in agricultural applications. Management of the DOE program in direct heating applications has been delegated to the Agricultural Research Service (ARS) of the Department of Agriculture, which cooperates with state agricultural experiment stations, ARS laboratories, universities, and industry. DOE (through the Agricultural and Industrial Process Heat Branch) maintains a monitoring role in the program. The early emphasis in the process heat program has been on state-of-the-art components for applications.

The Federal program in irrigation applications has been the responsibility of the Solar Thermal Power Systems Division in its applications support program. One project has been completed and one has been proposed to demonstrate the feasibility of distributed collector system to power small and large irrigation pumps in the southwestern United States. Research and development in concentrating collectors and organic Rankine-cycle engines is included in this program.

Expenditures in these two programs in FY77 (by application) are listed in Table 10-2.

Table 10-2. FY77 EXPENDITURES FOR SELECTED AGRICULTURAL APPLICATIONS

(in thousands of dollars)

Crop Drying	57
Greenhouses	596
Irrigation Projects	235
Grain Drying	530
Livestock Production	456
Food Processing	254
	2,428

Source: ERDA 77-72, June 1977.

Value of contracts awarded for research, development, and demonstration in agricultural heating was distributed in the following way: 74% to universities, 16% to USDA labs or to ARS, 9% to private laboratories or organizations, and 1% to state agricultural experiment stations.

Principal Developments in FY77

- An irrigation demonstration project at a site near Willard, N. Mex. became operational, supplying 630 gallons per minute from a deep well with a 25 hp solar-powered pump.

- A contract was let for a second irrigation demonstration project at a site near Coolidge, Ariz. which will have a 150 kW pump.

- Fifteen solar grain drying projects were funded.

- Eight crop drying projects were funded.

- Twelve projects in the use of solar energy in livestock production were funded.

- Thirteen projects were funded in the construction, design and optimization of greenhouses and greenhouse/residential combinations.

- Six projects to assess the feasibility and to propose designs and demonstrations for solar heating of food processes were funded.

- Reports on five solar greenhouse demonstrations were presented at a DOE-sponsored workshop on agricultural and industrial process heat. Low-cost systems exhibiting potential cost-effectiveness were emphasized.

Advantages of Solar Agricultural Systems

- The temperature requirements for agricultural heating frequently are modest. Therefore, applications can rely on current technology and are not dependent on high-cost and technically completed systems. There are significant possibilities for individually designed, very low-cost systems which can be constructed by farmers with technical assistance from the extension service.

- Land area is readily available for collector installation.

- In most cases, solar systems will be competing with LPG or electricity. Both of these energy sources are now relatively expensive (compared to other fossil fuels) and likely to increase in cost.

- Agricultural applications are often seasonal. Multiple-use solar systems tied to total farmstead energy management are likely to be cost-effective.

- Farmers' experience with solar energy in natural solar driers and greenhouse systems, as well as with commercial "active" units, is likely to encourage use of new solar systems on the farm. Farmers may be less resistant to the concept of diffuse or intermittent sources of energy than industrial or residential users.

- There exists significant potential for the use of solar thermal energy in agricultural applications abroad. For example, an assessment of priorities for solar energy in West and Central Africa places irrigation and pumping systems (0.5-10 hp) first, and solar distillation third.[7] Agricultural energy requirements are large in LDCs. There is widespread familiarity with solar crop and grain drying. The export of low-cost technology for solar agricultural applications could be beneficial to international relations and to export trade.

Problems, Uncertainties, Dissenting Views

Agricultural applications of solar thermal energy, at least in terms of direct use of solar heat, have been closely associated with the use of solar energy for industrial process heat. Most market penetration studies and critiques of Federal programs have dealt with the agricultural and industrial sectors as a single entity, though it is increasingly clear that the nature of applications, technology, and problems may be strikingly dissimilar in the two sectors. The rate of penetration of solar technology is likely to be greater in the agricultural than in the industrial sector though agriculture's share of total energy consumption is much smaller. The following problems and uncertainties have been cited:

- The potential impact of solar agricultural applications on total United States energy requirements will be small (maximum of about 0.5%).

- Most favorable areas of insolation do not correspond to areas of highest demand for direct heating; however, the correspondence is (in general) better than for the industrial market and there is a nearly perfect correspondence for irrigation systems.

- There is a lack of experienced and nationally recognized design, installation, and maintenance organizations to rapidly extend the use of solar agricultural equipment. In addition, farmers, ranchers, and agricultural advisors need to be educated about the use of solar thermal energy in specific climates and applications. A Federal demonstration and assistance program, with greater visibility, will help increase acceptance of solar systems. However, poor performance in publicly or privately funded applications will have a negative impact on acceptance.

- There are two constraints on the rapid commercialization of agricultural systems. First, the supply of durable, low-temperature collectors for agricultural use may be restricted. Second, low crop prices may put severe constraints on capital available for investment in new systems; government loan, grant or guarantee programs specifically directed at agriculture may be required.

- Although low-temperature nonstorage systems are currently the best alternative in drying systems, a conventionally-fueled backup or boosting burner will be required to complete drying of certain grains. As a result, returns of the solar system are sometimes only credited to fuel savings, and cost-effectiveness may appear marginal.

- Two solar thermal irrigation projects indicate that equipment costs are still too high to justify widespread private investment in solar irrigation. Two major components will require significant cost reduction (and/or efficiency improvements). Specially designed organic Rankine-cycle turbines and gear boxes are expensive items of equipment. In addition, engine efficiency was only 15% at design output when the collector field was operating at 450°F in the Willard, N. Mex. demonstration project. Concentrating collectors (designed for 600°F operation) must also be reduced in cost by a substantial degree. The Gila Bend irrigation project will cost nearly $2.5 million (private).[8] Some analysts believe solar irrigation systems will be economical only in areas where no alternative fuels are available (i.e., remote sites).

- If solar system use is strictly seasonal, and no provision for multiple-use is made, payback may be hindered by returns (in terms of fuel savings) accumulated over only a part of the year.

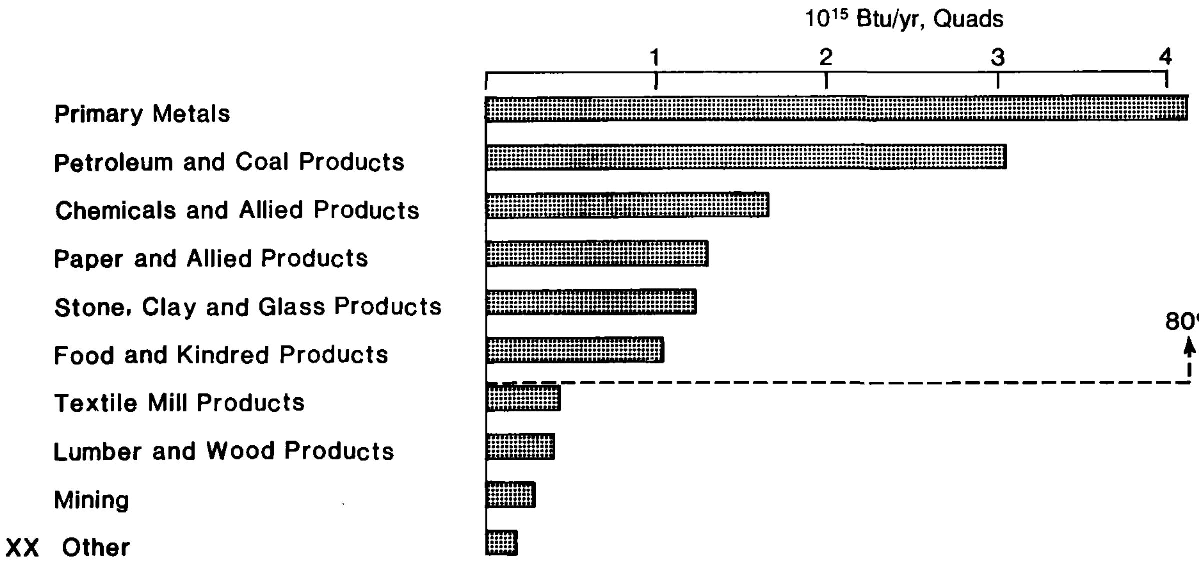
There seems to be less disagreement among researchers in agricultural applications than among those in industrial applications of solar energy. Overall, the market potential of agricultural applications has not received the attention it deserves. Although MITRE/METREK analysis indicates a greater market potential for high-temperature industrial process heat than for low-temperature agricultural applications, DOE suggests that 50% of the agricultural heating market could be served by solar energy by 2000—a significant opportunity for solar commercialization. While no real opposition exists to agricultural solar energy, positive support is needed to accelerate commercialization of this technology.

INDUSTRIAL PROCESS HEAT APPLICATIONS

Basic Technical Description

Industrial process heat is defined as thermal energy used directly in

Figure 10-4. PROCESS HEAT REQUIREMENTS IN MAJOR INDUSTRIAL GROUPS*



*Over 80% of the demand is concentrated in six industrial categories.

the preparation and/or treatment of materials and goods produced by mining and manufacturing processes. Though process heat is required in nearly every type of industry, over 80% of the demand is concentrated in only six major industrial categories. (See Figure 10-4.) Process heat energy can be supplied through a transfer fluid or by direct heating. In practice, heating fluids include hot water, low-pressure steam, or hot, dry air. Surveys of the relative quantity of heat energy required at various temperatures in the industrial sector have shown that a significant fraction of industrial process heat is used at temperatures within the operating range of currently distributed solar collector technology. For example, 40% of the total industrial process heat demand for direct applications and preheating occurs below 600°F (Figure 10-5).

As a result, the possibility of using solar collectors to heat a fluid (such as water) and subsequently transfer heat from this fluid, either directly or via heat exchangers, to materials in process appears quite feasible. Conventional flat-plate collectors may be satisfactory in many low-temperature applications, but the use of various forms of solar concentrators will be necessary in the majority of industrial applications where higher temperatures are required. The development of cost-effective concentrating collectors therefore deserves attention.

In addition, new concepts of large-area, shallow solar ponds to provide low-temperature hot water and of evacuated-tube banks for higher-temperature fluids are likely to find application. Hybrid systems may provide better performance in areas of variable cloudiness or for processes with a broad range of temperature tolerance. Such systems, consisting of collector fields of flat plates and parabolic troughs, have already been designed and installed for industrial applications.

Industrial applications will normally require much larger areas of collectors in order to provide substantial quantities of heat. The principles of system operation will be similar to those for residential heating and hot water, but because of strict reliability requirements, a smaller fraction of the annual heat required will probably be supplied. Consequently, long-term storage will not be required. Most near-term industrial solar systems will probably provide only one to two days of storage in order to collect solar energy on idle weekends or provide no storage and act merely as fuel-savers which are supplemental to full-capacity, conventional process heat systems.

One can identify four generic categories of industrial process heat applications:

HOT WATER

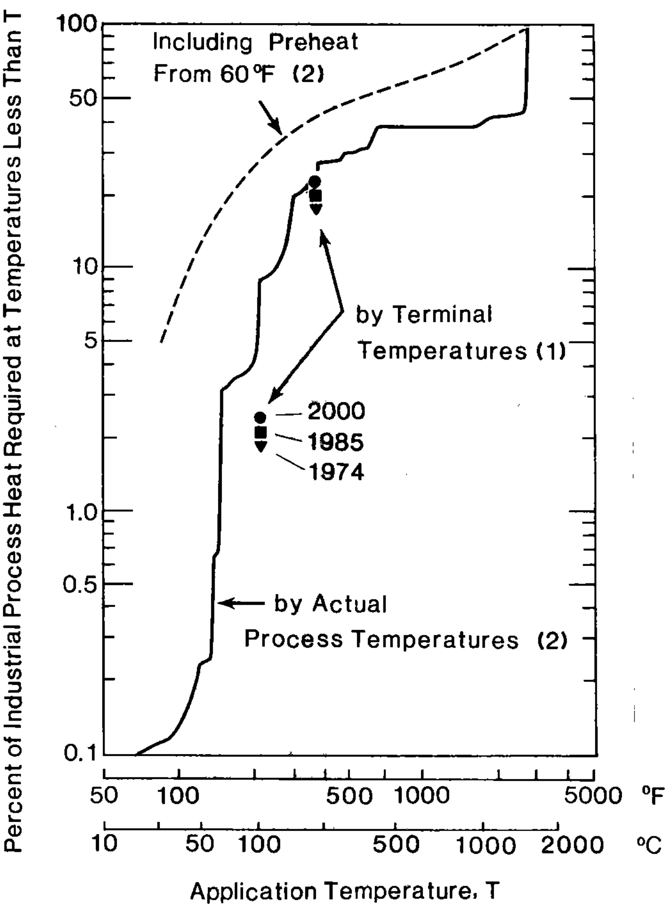
Large amounts of heated water at temperatures between 120°F and 212°F are required in almost every industry for cooking, washing, bleaching, anodizing, refining, and related uses. Hot water requirements are approximately 2% of the direct total industrial process heat demand, amounting to 0.2 Quads of energy at a temperature level which can be easily supplied by current solar technology. Preheating water to provide boiler feed for higher temperature industrial processes probably accounts for 3.0 Quads of energy. Hot water solar systems may be applicable to industrial preheating, although indications of prospects for boiler preheating (in electric utility generation, for example,) are discouraging.

Hot water may be supplied by directly heating water in the absorber tubes of flat-plate, evacuated tube, or concentrating collectors and piping this water to the process terminals. If processing standards require uncontaminated water, a separate fluid may be piped through the collector field and then used to heat potable water via a heat exchanger. Large, shallow solar ponds may also be used to heat substantial volumes of water for batch usage. Heated water is often drained into insulated storage tanks at the end of a day, although it may be economical to provide night insulation on the ponds for integral storage.

STEAM

Except for direct process heat above 350°F, the demand for process

Figure 10-5. CUMULATIVE DISTRIBUTION OF PROCESS HEAT REQUIREMENTS (2)



Notes: Data Points Refer to:

(1) Hall, E., *Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat*, Report: ERDA TID-27348-1, Columbus: Battelle Columbus Laboratories, 1977.

(2) Fraser, M. D., *Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat*, Report: ERDA/COO/2891-1, Warrenton: InterTechnology Corp., February 1977.

steam is the largest single process heat requirement of the industrial sector. Somewhat more than 6 Quads are required for steam production and over 80% of this requirement is for low-pressure saturated steam below 350°F. In fact, standard industrial requirements are often for saturated steam at 100 psig, corresponding to a saturation temperature of about 340°F. Steam at this temperature can be produced in a solar system principally in two ways. Pressurized water may be circulated in the collector field and then flashed into steam in a low-pressure chamber. Alternatively, a heat transfer fluid capable of higher temperature operation may be circulated in the collector field, and then fed to a steam generator, where the fluid serves as a heat source to produce the steam.

Because of the higher temperatures required, industrial steam applications will normally require concentrating collectors, such as a parabolic trough, or certain nonimaging, high-temperature collectors such as the evacuated tube.

DRYING/DEHYDRATION

Nearly 1.4 Quads of energy are required for the production of hot, dry air in industrial processes below about 350°F. This air is required in a large variety of drying and dehydration operations; many applying to food processing or crop drying. Air may be heated to this temperature directly in collector systems designed to handle air as a circulating fluid. Alternatively, a liquid circulating fluid may be used and pumped through an air heat exchanger to heat ambient air.

DIRECT PROCESS HEAT

High-temperature, direct process heat accounts for an overwhelming fraction of industrial process heat. Sixty percent of all industrial heat is required at high temperatures (defined here as an application temperature of 650°F and above); and the major portion of this requirement is supplied as direct refractory heat in industries such as primary metals, glass, Portland cement, etc. Except for very small-scale solar furnace applications, it is unlikely that solar energy will be used for process heating at the temperatures in the near future. However, recent research into high-temperature, distributed-focus solar concentrators lends some hope for direct solar heating in certain processes. For instance, the receiver tube of a powerful tracking concentrator might be used as a reactor for synthetic fuel production from biomass at temperatures on the order of 1000°F.

In addition, preheating of combustion air, as is done in at least one industrial demonstration today, might provide significant fuel savings without requiring inefficient high-temperature collector operation.

Sample applications of industrial process heat are shown in Table 10-3.

Federal Program Goals

- Develop designs, test and demonstrate solar industrial process heat systems exhibiting outstanding potential for providing process heat, and to identify problems and barriers to development for those systems.
- Encourage development of collectors and storage systems capable of advancing solar process heat system performance and temperature range.
- Show to potential users of solar energy systems, via a demonstration and testing program the economic and technical advantages of applying solar process heat systems to their industrial requirements.
- Encourage the adoption of various investment incentives by the Federal government.
- Encourage commercial production and development of solar components via a demonstration and testing program.
- Assess the potential for application of solar energy to industrial process heat and identify those processes and locations where solar energy can supply a significant amount of process energy needs.

Table 10-3. INDUSTRIAL APPLICATIONS

Location		Contractor/Sponsor	Solar Collector/Process/Company	Status
Athens,	AL*	Teledyne-Brown/DOE	SSP/Hot process water/Sweet Sue Kitchens	Design Only
Decatur,	AL	Teledyne-Brown/DOE	FPA/Soybean drying/Gold Kist	Mid-1978
Fairfax,	AL	Honeywell, Inc./DOE	CS/Cylindrical can dryers/West Point-Pepperell	Mid-1978
El Centro,	CA	Jacobs Engineering/DOE	CW/Industrial laundry/American Linen Supply	Design Only
Fresno,	CA	Cal Poly State Univ./DOE	FPA/Fruit drying/L&P Foods	Early 1978
Gilroy,	CA	Trident Engineering/DOE	FPA/Onion drying/Gilroy Foods	Design Only
Sacramento,	CA	Aerotherm-Acurex/DOE	CW/Canwashing/Campbell Soup	Operational
Lawrence,	KS	MRI/DOE	CA/Alfalfa drying/Western Alfalfa Corp.	Design Only
Canton,	MS	Lockheed-Huntsville/DOE	FPW/Lumber Kiln/LaCour Kiln Service	Operational
Grants,	NM	LLL/DOE	SSP/Uranium ore processing/Sohio	Operational
York,	PA	AAI Corp./DOE	LA/Block curing/York Bldg. Products	Mid-1978
LaFrance,	SC	General Electric /DOE	ET/Dye beck/Riegel Textile Corp.	Mid-1978

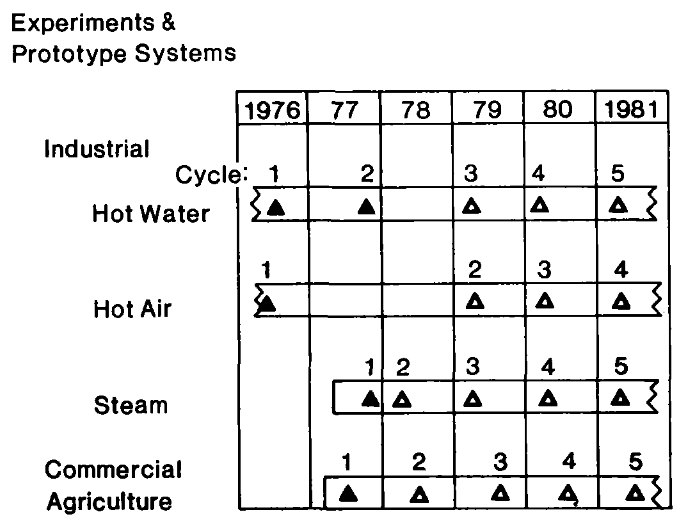
*Key to acronyms:

CA	Parabolic trough concentrator using air
CS	Parabolic trough concentrator using steam
CW	Parabolic trough concentrator using water
ET	Evacuated tube collector
FPA	Flat-plate air system
FPW	Flat-plate water system
LA	Linear array, fixed receiver
SSP	Shallow solar pond

Description of the Federal Program

The DOE program has been concentrating on an aggressive demonstration plan, calculated to encourage system and component develoment, while demonstrating to private industrial investors the near-term capabilities of solar industrial process heat (Figure 10-6). The Federal role in funding demonstrations has been to reduce the risk associated with R&D and installation of such systems, and thus to accelerate industrial acceptance. Funding has been geared to encourage state-of-the-art component applications; long-term component R&D has been primarily funded through other programs in solar heating and cooling, and solar thermal power systems. The 1977 budget for industrial applications was less than 2% of the total budget of the ERDA Division of Solar Energy. Of a total expenditure of some $5.34 millin, $3.86 million (72%) was spent on demonstrations, and $645,000 (12%) was spent in supporting major studies of the process heat sector. Approximately $800,000 (15%) was spent by Agricultural and Industrial Process Heat Program in support of research programs in other areas or in the development of systems and/or components applicable to needs in these areas. The remaining sum was directed to the annual workshop.[9]

Figure 10-6. INDUSTRIAL PROCESS HEAT FEDERAL PROGRAM MILESTONES



Source: ERDA 77-72, "Solar Energy for Agriculture and Industrial Process Heat, Program Summary," June 1977.

Principal Developments in FY77

- Designs were completed for ten industrial process heat system demonstrations.
- Conceptual design was completed for the installation of a shallow solar pond at a food processing plant in Athens, Alabama.
- Eight selected solar process heat application demonstrations were under construction during the year.
- Two privately funded solar industrial process heat systems were operating or planned in FY77.
- The Second Annual Solar Industrial Process Heat Symposium

was held in College Park, Maryland, in September, 1977. Reports on DOE-funded demonstrations were given to assembled researchers, industrialists, builders and collector manufacturers.

- Two studies concerning the application of solar energy to industrial processes and assessing the technical and economic potential of solar industrial process heat were completed. The studies provided substantial industrial process heat data and a clear interpretation of the temperature range of industrial requirements.[10]

Problems, Uncertainties, Dissenting Views

The technical feasibility of solar systems to provide industrial process heat at temperatures below approximately 350°F is easily demonstrable. Providing process heat at higher temperatures can be demonstrated in certain cases; but in others, application must await technical advances in high-temperature coatings, insulation, and equipment design. Current technology to provide preheating energy may serve some high-temperature process heat demands; however, economic feasibility for solar industrial process heat is more difficult to demonstrate, and considerable uncertainty exists regarding the future economic viability of solar industrial process heat.

Differing views of industrial process heat's potential are indicated by two major ERDA-sponsored studies in Figure 10-5. Among the general studies specifically directed toward a market analysis for solar energy (EEA and METREK)[11], differences can be attributed to analytical discrepancies in:

- market segmentation;
- solar technology suitability;
- solar equipment projected costs;
- conventional fuel cost projections;
- conservation techniques as opposed to solar energy;
- methodologies for projecting market capture.

InterTechnology estimates of the market share for solar industrial process heat are made only on the basis of technical performance and strict marginal economic analysis and, therefore, might be viewed as an upper limit (without substantial incentives) to the application of solar energy in this sector. The market penetration analyses of EEA and METREK, however, both depend on the analysis by InterTechnology of process demands at various temperatures. METREK assumes a possible market for solar energy in providing preheat to high-temperature processes. EEA disregards this potential market, assuming that waste heat will be used in all cases. This difference in market potential estimates is significant and is reflected in the optimistic/pessimistic views expressed.

Limitations in the application of solar industrial process heat can be attributed to the following factors:

- Application of solar energy must, in general, compete with cheaper alternatives, including coal, oil, gas, and conservation measures.

- Industry requires a very short payback period (i.e., high return on investment) on capital projects.

- Collector costs have not reached a level characteristic of a mature industry and, more importantly, system construction experience is not sufficient to reflect eventual competitive levels of system costs.

- Federal fuel-use tax credits are a disincentive to solar investment.

- Unless extremely large areas of collectors are considered, the impact of solar process heat is likely to be a small fraction of the total required energy for a given industrial plant. There is a temptation to neglect systems with such a small impact among large industrial energy users.

- The limitations on operating temperature for current solar systems exclude a large portion of the process heat market where direct applications are considered and make recuperative use of initial high-temperature heat a more economic alternative for low-temperature needs in many industries. However, a substantial portion of high-temperature demand can be attributed to preheating over a lower temperature range.

- The costs of idle manufacturing capital and labor are such as to require high system reliability. If long-term storage (which is costly) is not considered, then full capacity backup must be provided, making the only return on solar system investment equal to the annual savings on the fuel bill for conventional systems. The inclination of any industry to seek these savings may be a function of the energy intensiveness of product manufacture.

In addition, the wide application of solar industrial process heat will face a number of nontechnical problems, such as:

- reluctance of industry to accept "new venture" technology until widely demonstrated and shown reliable;
- tendency of industry to remain with present heating systems or to consider energy conservation methods as an alternative to solar energy (particularly true when expansion of plant capacity is not anticipated;
- environmental and economic problems in devoting large areas of land to collector fields or, in retrofit applications, finding suitable land or roof area.

Solar industrial process heat also has certain advantages which may make its future more promising than what some recent studies indicate:

- Industrial loads are usually constant over the year; hence, solar process heat systems do not show the seasonal disadvantage of low solar input and high demand which is characteristic of solar space heating systems.

- The potential impact of solar process heat is much larger, in total energy demand terms, than the potential impact of residential solar heating.
- Greater amounts of capital are available in the industrial sector for system investment.
- Life-cycle costing is more acceptable in the industrial sector than in the residential sector. One would expect industrial managers to be more receptive to the concept of calculated future returns.
- Large-area collectors are applicable and may show cost advantages.
- Large-area solar systems may show cost advantages of scale in construction methods.
- Reductions in atmospheric and thermal pollution and enhancement of energy resource conservation may confer public relations benefits on companies adopting solar systems.
- Probable reductions in system costs and an escalation in alternative energy costs (in real terms) may offer investment advantages in the future.
- Solar systems are less susceptible to potential supply interruptions than are conventional fossil fuels.
- Greater reliance on the life-cycle costing in industrial investment analysis may favor solar systems.
- There are significant prospects for "hybridization" of processing systems in order to make use of more efficient solar preheating for high-temperature processes.

Notes

[1]Federal Energy Administration and USDA, *Energy and U.S. Agriculture:* 1974 Data Base, FEA/D-76/459, Washington; September 1976.

[2]Ibid.

[3]A.B. and M.P. Meinel, *Applied Solar Energy* (Reading: Addison-Wesley, 1977), pp. 554-556.

[4]W. Roberts, "Islander Seeks Patent for Solar Irrigation Unit," *Grand Island Daily Independent,* November 14, 1977.

[5]National Academy of Science, *Solar Energy in Developing Countries,* PR-208550, Washington: March 1972.

[6]Meinel and Meinel, *Applied Solar Energy* (1977), pp. 554-556.

[7]National Academy of Science, *Solar Energy in Developing Countries* (March 1972).

[8]L. Listiak, "Sun Shines on Gila Bend Farm," *Yuma Daily Sun,* Yuma, Arizona, November 6, 1977, p. A-14.

[9]*Solar Energy for Agriculture and Industrial Process Heat:* Program Summary, ERDA 77-72, Washington: June 1977.

[10]*Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat,* Final Report (3 volumes), Battelle, TID-27348/1, Columbus, OH: Jan. 1977.

[11]*Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat,* InterTechnology Corp., C00/2829-76/1 Warrenton, VA: Feb. 1977.

11. PHOTOVOLTAICS (SOLAR CELLS)

BASIC TECHNICAL DESCRIPTION

Photovoltaic solar cells convert collected sunlight directly to electrical power. The physical properties of simiconductors, from which solar cells are made, permit these to function as pumps for electrical charge. One quantum of light falling on the cell can pump one electron through the attached lead wires and through any equipment using electricity.

The physics of solar cells limit the theoretically available electrical power to about ⅓ (33%) of the incoming solar power. In practice, effiiciencies of about ⅕ (20%) have been achieved with converters made of the semiconducting materials silicon and gallium arsenide. Such efficiencies make solar cells feasible for practical application. Silicon cells have achieved this status through 20 years of experience of deployment with satellites; the gallium arsenide cell constitutes a more recent development resulting from research in opto-electronic devices.

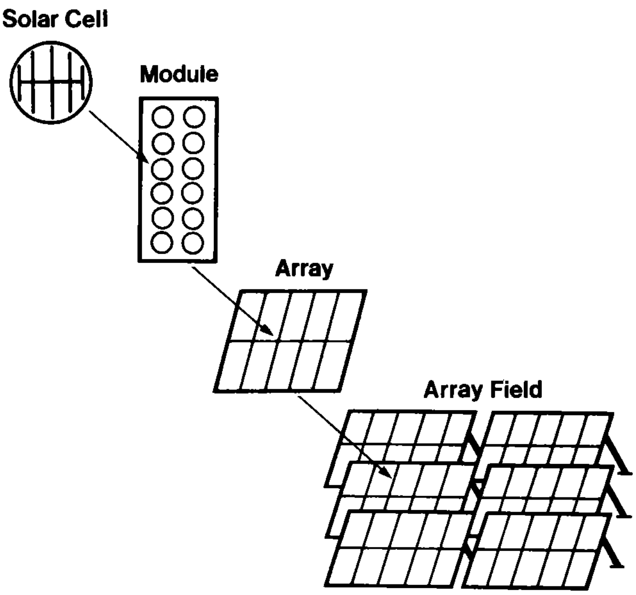
Demonstration of a useful efficiency is only the first, but indispensible, step toward the production and installation of economical solar cells. Technological pathways and costs are equally determined by availability of raw materials; purification; production of solar cell blanks in one of several forms and their processing to cells; manufacturing of modules and arrays, and their deployment in fields (see Figure 11-1). The secondary costs of electrical power control and storage also affect the economy of photovoltaics.

GOALS AND DESCRIPTION OF CURRENT PROGRAM

The goal is to produce photovoltaic installations at a price of $\$2/W_p$ generating capacity by 1982, and of $\$0.50/W_p$ by 1986 (a peak watt is produced at most intense sunshine; prices are in 1975 dollars).

The main thrust of the photovoltaics program is technology development; however, a second activity is cost reduction by rapidly accumulating silicon cell manufacturing experience through subsidized Federal purchases. Because no major new technologies are expected to be available for practical application by 1986, this purchase activity is supported by intense applications-oriented R&D for conventional cell manufacture. The policy of accelerated purchases and of focused R&D covers both deployment technologies; i.e., flat-plates and concentrators.

Figure 11-1. RELATIONSHIP OF PHOTOVOLTAIC CELL, MODULE, ARRAY, AND FIELD



Another photovoltaic program activity is concerned with R&D of new materials and devices for solar cells with the goal of developing less expensive alternatives to existing technologies.

Assessments and forecasts accompany the technical efforts. These studies consider the variety of scenarios associated with the development and introduction of photovoltaic power production. The main goals are identification of the optimum Federal support role and early identification of appropriate deployment strategies.

The recent experience with terrestrial photovoltaic systems has led to the initiation of ancillary projects in electrical power storage, the control of the photovoltaic direct current and its conversion to alternating current, the establishment of standards and calibration procedures, and other areas.

PRINCIPAL DEVELOPMENTS IN FY77

Single Crystal Silicon Flat-Plate

- Federal Procurement (200 kW). Six manufacturers were awarded contracts under a third Federal procurement. The average cost was slightly more than $11/kW$_p$ (1975 dollars, 28°C, FOB destination). The "learning curve data" presented in Figure 11-2 show that the cost of photovoltaic products has decreased steadily over the three procurements. The status of these costs compared to the DOE projection for photovoltaics is also shown in Figure 11-2.

- Silicon Ribbon. During FY77, the EFG ribbon program reported the successful growth of three ribbons simultaneously from the same replenishable melt. The 2 in. wide ribbons were fabricated into cells of 10.4% efficiency. Another major demonstration was the growth of five ribbons simultaneously in January 1978.

- Module Efficiencies. Maximum module efficiencies (which nominally have been in the 7-8% range) exceeding 10% were demonstrated.

Concentrator Cells/Systems

- Silicon Cells. Some progress was made toward the goal of developing high-efficiency cells and manufacturing processes. Developments included the improvement of the interdigitated back contact (IBC) cell, with 15% efficiency at 100 suns achieved. Concentrator cell designs were completed which adapt easily to production processing. Also, 0.3 Ω-cm n^+p cells with efficiencies exceeding, 15% under 100 suns were reported, and progress continued on a p^+nn^+ back surface field (BSF) cell, with 17% efficiency (1× concentration) attained. The successful fabrication of highlow emitter (HLE) cells was demonstrated with a 50× efficiency of 16.8% reported.

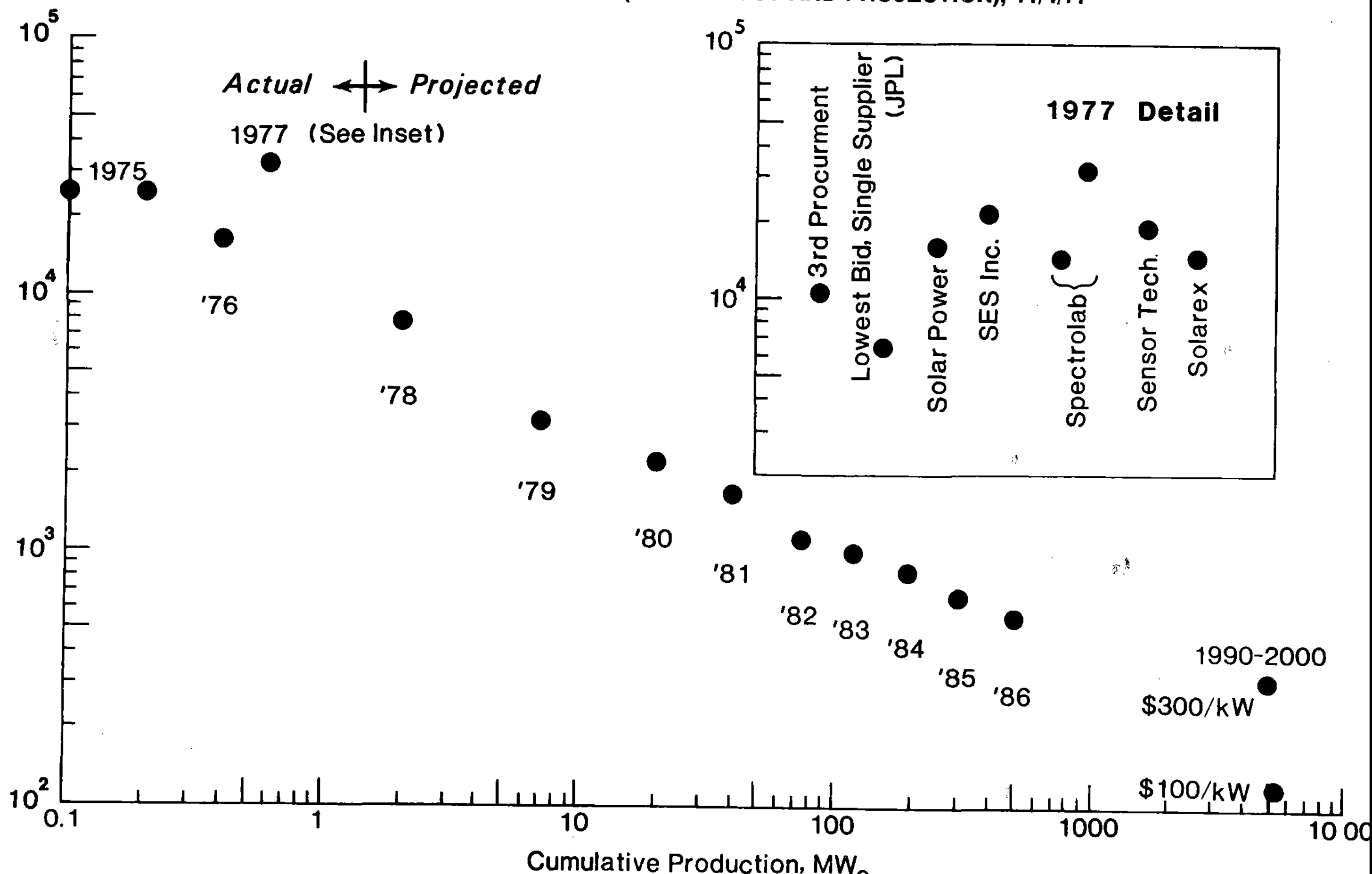
- Gallium Arsenide Cells. Several cells exceeding 23% conversion efficiency were reported. This included a 23.3% $Al_{1-x}Ga_xAs/GaAs$ cell measured under 945 suns. This same device had a 21.8% efficiency under 1680× concentration.

- Array Development. Contracts were awarded to develop 10 kW concentrator arrays.

Advanced Materials and Device R&D

- Cu_2S/CdS Thin Film Cells. Device efficiencies exceeding

Figure 11-2. PHOTOVOLTAIC SYSTEM (ARRAY COST AND PROJECTION), 11/4/77



8.5% were reported. Work was initiated on $Cu_2S/Cd(Zn)S$ cells, and devices with efficiencies above 6% were demonstrated.

- Amorphous Silicon. Device efficiencies approaching 6% were achieved. Work is now centered on larger area devices (10 cm x 10 cm).

- Polycrystalline Silicon. Polycrystalline silicon devices were produced with efficiencies exceeding 7% during FY77. Efficiencies greater than 15% have been reported by Solarex in FY78.

- Thin Film Devices. Progress continued in the development of intermediate-efficiency devices using gallium arsenide, indium phosphide, copper-ternaries, silicon, and zinc phosphide. Progress was reported in homojunction, heterojunction, Schottky barrier, and metal-insulator semiconductor (MIS) devices.

Assessments

- Cell Manufacturing Technology. Major studies and reports of cell manufacturing costs, detailing step-by-step processing expense, were published.

- Conceptual Design. Conceptual design studies of photovoltaic systems for an on-site residence, central power station, and intermediate power system were reported.

- Market Analysis. Market analysis assessments for photovoltaic systems were prepared.

Demonstrations

- Mead, Nebraska, Irrigation Project. This demonstration uses some 100,000 single crystal silicon solar cells and provides 25 kW_p for powering irrigation pumps. The system is used to dry the crops after the growing season.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

The overriding problem of photovoltaic solar energy conversion is that of cost. At present, nearly every one of the materials, manufacturing steps, or support structures is too expensive to make solar electricity compete with commercially-produced electric power. However, in each case, less costly developments or alternatives have been identified and are being pursued. Consequently, the initial skepticism over price goals is giving way to one about their timely fulfillment.

Substantial uncertainties exist about long-range technological alternatives for cost reduction below the 1986 goal. This is not surprising in view of the short history of vigorous photovoltaic R&D.

The modular nature of photovoltaic converters may lead to an electricity cost which depends little on the size of the installation. Thus PV represents an opportunity for decentralized generation of energy as well as the more traditional central power generation. The uncertainty introduced by these broadening markets has been perceived as a potential problem.

Controversy over the direction of photovoltaic development includes disagreement about the optimum technical options, about the attainability of cost goals, and about the practicality of widespread photovoltaic power generation. The wide spectrum of views on these issues is not surprising in light of the technological and social break with conventional modes of power generation which solar cells provide.

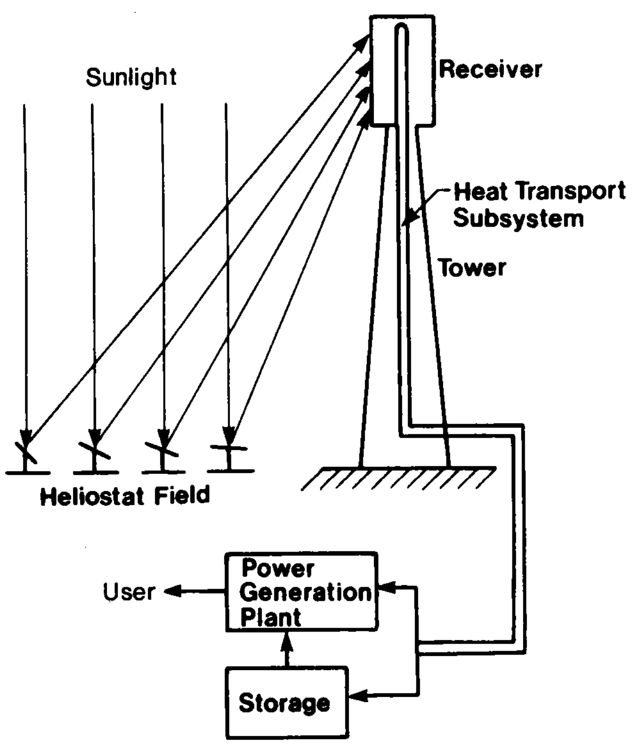
12. SOLAR THERMAL POWER SYSTEMS

BASIC TECHNICAL DESCRIPTION

Solar thermal power generation involves the collection and concentration of the sun's rays, conversion to heat, and finally, conversion of the heat to electricity. Figure 12-1 shows the major subsystems in a large, central receiver, solar thermal power system. This is only one of the four categories of solar thermal power systems being pursued:

- large centralized plants (10+ MW_e);
- Small, decentralized plants (1-10 MW_e);
- total energy systems including small community systems;
- irrigation systems (25-500 kW_e).

Figure 12-1. CENTRAL RECEIVER SOLAR THERMAL POWER PLANT



The central receiver plant has had the greatest R&D priority because it has been considered closest to economic competitiveness for utility grid electric power. This central station application dominates present national consumption of electricity. The second category (small power plants) has the advantages of siting flexibility and savings in transmission and distribution costs. Its modularity makes it flexible for a variety of applications. Total energy systems not only generate electrical output, but use the heat normally rejected to the atmosphere to meet thermal energy needs. This results in a much more efficient use of energy and in an energy cost reduction. Irrigation systems are characteristic of the smallest type of solar thermal plant under development by the Government, ranging in size from 25-500 kW_e. Smaller systems are being produced by a number of industrial organizations.

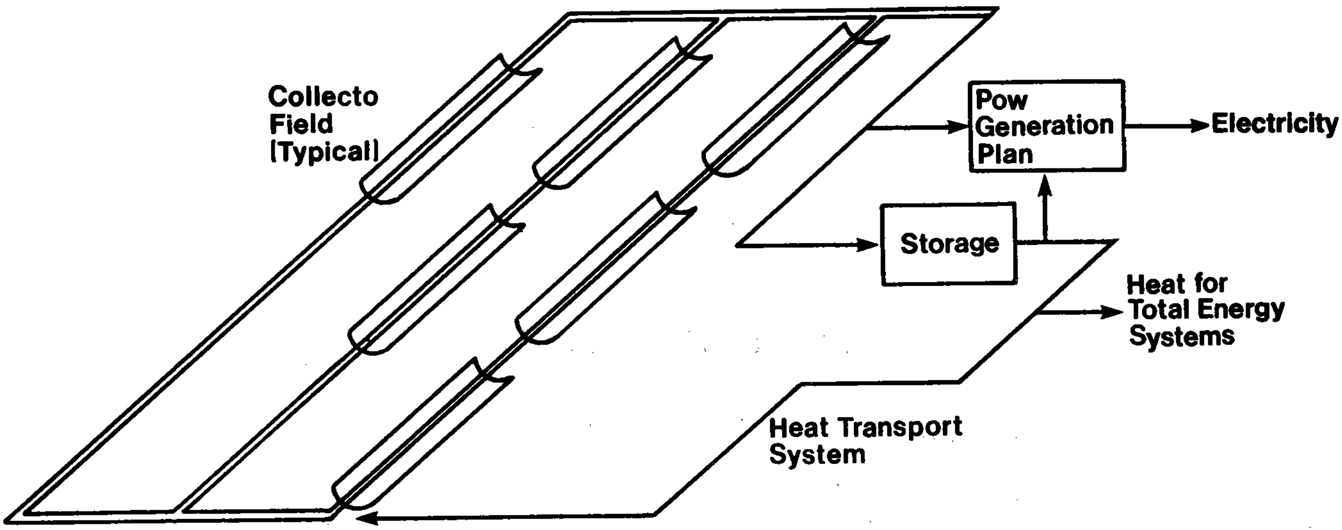
Central Receiver System

In these systems, the solar energy is reflected by mirrors called "heliostats" to an energy receiver located on the top of a support tower. The optical energy is converted at the receiver to heat, which is transferred by transport systems using either water, steam, molten salt, liquid metal, or gas. This heated fluid is then used to drive a heat engine/generator to produce electricity. Thermal energy is stored to smooth out input to the heat engine and to extend plant operation beyond the time of sun availability. The main advantage of the central receiver concept is the high temperature made possible by solar concentration of 1000 times. Systems are being designed to produce super-heated steam at 950°F for use with conventional steam turbine-generator equipment. Brayton cycle systems operating at 1500°F or more also are being considered.

Decentralized Systems

Decentralized systems offer the option of meeting more localized residential, commercial, or industrial electric and thermal loads. Distributed systems differ from central receiver systems in having the collectors themselves convert solar energy to thermal energy. The thermal energy is then transmitted via a matrix of insulated piping to central power conversion equipment by air, water or steam, liquid metal, or molten salt. Electricity is generated at the central energy conversion plant as shown in Figure 12.2.

Figure 12-2. TYPICAL DISTRIBUTED SOLAR THERMAL ENERGY SYSTEM



The different types of solar collectors which can be used for decentralized systems include flat plates, parabolic troughs, paraboloidal dishes, and even small versions of the central receiver. Flat-plate systems have the lowest collection efficiencies and the lowest temperature capability (200-500°F); thus they require large areas of collectors and land compared to other systems. As the collector operating temperature increases for each type of collector, the system efficiency increases, and lamp and mirror area requirements decrease.

Temperatures are typically 400-800°F for one-axis, tracking, parabolic trough systems and in excess of 1000°F for two-axis, tracking, paraboloidal dish systems.

An alternative to using thermal transport from a field to a central plant is the paraboloidal dish, small heat engine system with electric transport. A small heat engine, such as a Brayton or even a Stirling engine, is mounted on or near each high-performance paraboloidal dish. The engine drives a generator, producing electricity at each collector. These small Brayton and Stirling engines are not as readily available as the larger, steam turbine plant. External storage is used in the form of batteries, pumped hydro, etc.

Total Energy Systems

Total energy systems are designed to provide both electrical and thermal power to the user. Since total energy systems have been considered for use with specific buildings having small electric and heating loads, these systems tend to be variations of distributed solar thermal systems. The one-axis, tracking, parabolic trough collectors are easier to build as part of a building than are the two-axis, paraboloid dish or the central receiver on a tower. However, both the paraboloidal dish and small central receiver can be used for total energy systems; the choice depends on size, economics, site integration, and other factors. Total energy systems are also being tested using flat-plate or concentrator types of photovoltaics. A large example of the latter is being implemented in Arkansas' Mississippi County Community College (MC^3).

Irrigation Systems

The early irrigation systems have used the parabolic trough, distributed systems, coupled with an organic, Rankine turbine-generator, to drive an electric pump. The largest system built to date powers a 25 hp pump; however, a 250 hp system currently is being designed. Both paraboloidal dish and small, central receiver are candidates for irrigation power.

GOALS AND DESCRIPTION OF THE CURRENT FEDERAL PROGRAM

The objectives of the effort to commercialize solar thermal power systems are:

- initial commercial implementation of dispersed, thermal power systems by mid-1980s;
- establishment of thermal power systems as an economical generation resource, for use by electric utilities in the late 1980s.

To meet these objectives, three parallel paths are being pursued:

- central applications;
- dispersed applications;
- advanced technology.

The major emphasis in the central applications program is in the large, central receiver system. The dispersed applications program involves small power systems (1-10 MW_e modular systems), irrigation systems, and total energy systems. Advanced technology supports both program areas with technology and advanced systems development.

The FY77 and FY78 budgets for these areas are in Table 12-1:

Table 12-1. FY77 AND FY78 BUDGETS FOR SOLAR THERMAL CENTRAL APPLICATIONS, DISPERSED APPLICATIONS, AND ADVANCED TECHNOLOGY

	FY77 M $	FY78 M $
Central Applications	21.5	22.2
Dispersed Applications	20.1	28.1
Advanced Technology	7.4	9.8
Total	49.0	60.1

PRINCIPAL DEVELOPMENTS IN FY77

Central Applications

- Design studies for 10 MW_e plant were completed.
- System design for 10 MW_e demonstration plant was selected.
- Studies were begun on advanced, second-generation power plants and subsystems.
- Initial testing was done of 5 MW_t rated facility at Albuquerque, New Mexico.

Dispersed Applications

- Solar total energy test facility at Sandia became operational.
- Two large scale (greater than 100 kW) total energy experiments were planned at Fort Hood, Texas, and Shenandoah, Georgia.
- A 1 MW_e small community power system program was initiated at JPL.
- A 25 hp irrigation facility became operational at Willard, New Mexico. This was the first of two irrigation experiments scheduled for operation in the near term.

Advanced Technology

- Small (400 kW_t) central receiver test facility became operational at Atlanta, Georgia.
- Advanced technology work was initiated at JPL on distributed systems.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Still unresolved questions surrounding solar thermal power systems are as follows:

Economic Feasibility Issues

- Can solar collector subsystem costs be reduced to make solar plants competitive with future costs of conventional power? (Note that costs have been decreasing; installed trough costs are now below $18/ft^2.)
- Can low-cost storage systems be developed to increase use of solar plants?

Distributed Receiver vs. Central Receiver Issues

- Do scaling factors favor one over the other for certain size ranges in terms of $/MBtu or ¢/kWh?
- How will the plant aesthetics, modularity, and adaptability to various applications, use of regularly or irregularly shaped land, building time, operating complexity, and operating and maintenance costs affect the choice of central vs. distributed?

Utility vs. Onsite Power Generation Issues

- Which is less costly?
- Who owns and maintains the onsite systems?
- What is the impact of onsite power on utility grid operation and reserve capacity?
- What are the social implications of dispersed vs. central power?

Geographic Applicability Issue

- Can system improvements be made to increase their useful geographic area beyond the Southwest?

13. WIND ENERGY

BACKGROUND

During the Middle Ages in Europe, manor rights usually included the right to prohibit construction of windmills. This compelled the tenants to have their grain ground by the lord of the manor. Other legal requirements banned planting of trees near windmills to insure "free access to the wind." Similar laws are still enforced in Holland. By the 14th Century, the Dutch had improved windmill designs and made extensive use of windmills to drain marshes of the Rhine delta. Around 1600, the first paper mill powered by wind was built in Holland to meet the great demands for paper created by the invention of the printing press. Over 20 windmills of about 40 kW each were used to drain Beemster Polder. At the end of the 16th Century, sawmills in Holland were powered by the wind and used to process imported timber. In Denmark, toward the end of the 19th Century, there were 3000 industrial windmills and 30,000 other types in use for homes and farms. These had a total power output of about 200 MW.

More than 6 million small windmills (less than 1 kW) were used in the United States since the 1850s to pump water and to generate electricity. Roughly 150,000 are still in operation.[1] Such machines produced about 1 billion kWh of energy annually as early as 1860.

Sales of the 1879 windmill industry were about $1 million, increasing to about $10 million by 1919. In 1889 there were 77 windmill factories in the United States, but by 1919 this number had decreased to only 31.[2] By 1900, windmills had become a significant factor in exports, and State Department consuls reported substantial demands for American windmills nearly everywhere except in Europe.

Experiments with large wind power machines were also conducted prior to 1950. The largest wind machine ever built to generate electricity was the Smith-Putnam 1.25 MW unit installed in Vermont. This machine had a rotor diameter of 53 m. It delivered utility power intermittently from 1941 to 1945, when a damaged blade broke and could not be repaired because of wartime material shortages.

Large wind machines were used in other countries around 1955. Nearly 30,000 wind power plants were in operation in the U.S.S.R. The Gedser wind turbine was operated in Denmark until the 1960s.[3] It could produce 200 kW of electrical power, had a rotor 27 m in diameter, and produced 400,000 kWh of electrical energy annually. However, the U.S. interest in wind power generally declined in the 25 years following 1950, and only recently has serious attention again been given to large scale collection of energy from the wind.

BASIC TECHNICAL DESCRIPTION

The wind derives its energy from the solar radiation that reaches the Earth's surface. Uneven heating of the Earth from the equator to the poles and over the oceans and the continents drives the motions of the atmosphere. The wind resource is difficult to determine precisely, and some published estimates of available wind energy differ by a factor of 10,000. A reasonable estimate between these two extremes would place the *maximum* U.S. resource at roughly 2 TW—approximately equal to our 1972 mean rate of energy usage from *all* sources.[4] However, this would require using wind turbines thinly scattered over 3% of the U.S. land area with the best winds—a total area equal in size to the state of Colorado. Still, only a very small fraction of this total land area would be dedicated to the machines; also, the machines are compatible with other land uses, e.g., agriculture. The ultimate amount of wind energy that will be used is difficult to predict; but the resource is large, and the technology is available if not yet optimum in terms of cost, durability, aesthetics, safety, and convenience.

The primary method proposed for using wind energy is to convert the kinetic energy of the wind into mechanical energy and then into electrical energy (minor efforts on other concepts are also in progress). Wind turbines are used to transform the air flow into rotary power. The major designs use:

- propellers with two, three, or many blades;
- vertical-axis Darrieus ("egg-beater") turbines;
- various types of concentrators to shape the airflow and increase turbine efficiency.

The energy output from a turbine is available in several forms. Mechanical energy can be used directly for several purposes, including heating and pumping of fluids. Electrical energy can be produced as direct (DC) or alternating (AC) current. DC electrical energy can be stored in batteries or used directly for heating and lighting. It might also be used to operate DC motors and appliances if these were more commonly available to the consumer or industry. AC electrical energy can be supplied to the utility grid and/or used directly at the point of collection. Because the wind is not always available the use of wind energy by utility grids presents special problems.

Modern designs to use wind power cover a wide range of sizes and technologies. The smallest machines being developed and sold today are smaller and considerably lighter than a subcompact car. The largest machines to be built in the Federal program are larger than a jumbo jet. Components of fiberglass, steel, aluminum, concrete, wood, plastics, and other materials are in use. Deployment plans range from units for a single home to multi-unit farms approaching the capacity of a nuclear power facility and billion dollar cost. The wind environment from which the power is to be taken varies just as much. Continental scale weather patterns and climatic trends will influence the energy collected. Wind fluctuations that occur as frequently as several times a second and wind variations over distances of only a few tens of meters will also affect machine performance and endurance.

GOALS AND CURRENT PROGRAM

The goals[5] of the Federal program are to:

- assess the national wind energy potential;
- determine expected regional needs, wind resources, and wind energy costs;
- study social and environmental issues;
- improve turbine siting methods and develop equipment design requirements;
- improve equipment performance and lower capital costs;
- explore innovative wind energy conversion methods;
- develop small machines (less than 100 kW) for agricultural or other uses;
- develop intermediate machines (100-1000 kW) for community, industrial, and utility uses;
- develop large machines (1 MW or more) for utility-grid applications.

The program is divided into five major program elements:

- Research;
- Small Scale Systems;
- 100-1000 kW Scale Systems;
- MW Scale Systems;
- Utility-Grid Arrays.

The research element is further subdivided into six areas;

- mission analysis (definition of the national resource, possible uses of wind energy, and R&D requirements);
- applications (economic and technical information for producing electric utility power);
- legal, social, environmental issues (local and Federal laws, public acceptance, environmental problems);
- wind characteristics (local and regional wind resources, equipment siting, wind measurements, and data);
- technology development (fabrication, components, mechanical and electrical subsystems);
- advanced and innovative concepts (non-propeller designs).

Organization of the program involves DOE, other Federal agencies, and several national laboratories. The DOE staff consists of five people—four professionals and one support staff. The laboratories are used to provide basic and applied research and to perform program management functions. Most of the R&D tasks are performed by various academic and industrial contractors. Large scale propeller-type systems are assigned to the NASA-Lewis Research Center. The Darrieus vertical-asix system is assigned to the Sandia Albuquerque Laboratory. Agricultural applications are assigned to the USDA. Small scale systems are assigned to the Rockwell International/Rocky Flats Plant. Wind characteristics studies are assigned to the Battelle Pacific Northwest Laboratory. Mission analysis and applications studies are assigned to the Charles Stark Draper Laboratory. Specific tasks in other areas and overall program management are handled at DOE.

Budget Appropriations[6] in FY77 and FY78 are presented in Table 13-1.

PRINCIPAL DEVELOPMENTS IN 1977

The Third Biennial Conference and Workshop on Wind Energy Conversion Systems was held in September 1977 to review program accomplishments in the last two years. The recent growth in U.S. wind energy research was reflected in the conference results. Papers covering approximately 90 studies were presented.[7] The subject areas included large and small wind turbines, economics, environmental and institutional concerns, meteorology and siting, large arrays of turbines, and innovative design concepts.

The final reports of two mission analysis studies[8] were also completed during FY77, giving estimates of the national wind resource, the future economic impact of wind energy, possible applications and markets, and initial cost projections for equipment.

Wind characteristics research in the last year[9] focused on improved

Table 13-1. WIND ENERGY BUDGET APPROPRIATIONS

	FY77 M$	FY77 %	FY78 M$	FY78 %
Research	7.9	35	9.3	28
Mission analysis	(1.3)*			
Applications	(0.2)			
Legal, social, environmental	(0.2)			
Wind characteristics	(1.9)			
Technology development	(2.6)			
Advanced systems	(1.7)			
Small Scale Systems	2.6	12	8.0	24
100 kW Scale Systems	3.4	15	2.9	9
MW Scale Systems	8.5	38	11.3	34
Utility-Grid Arrays	0.02	6	2.1	<1
Total	22.4		33.6	

*Numbers in parentheses are not included in total.
Source: DOE/ET-0022/1, p. 4.

methods for siting equipment, evaluation of data requirements for machine design, and localized wind resource assessment. Handbooks of information for use in machine design and performance evaluation were begun, and site selection handbooks were prepared for siting of both small and large turbines. Additional activities included the following:

- an eigenvector technique for analysis of vector wind fields was developed which may result in significant reductions in the number of computer simulations required in siting methodologies:
- a meteorological field experiment was conducted to obtain wind information on a physical scale directly associated with large propeller-type wind turbines;
- a synthesis of three previous National Wind Energy Assessments produced maps estimating the annual and seasonal distributions of wind energy in the contiguous United States.

Development of 100 kW and MW scale propeller-type wind turbines progressed through work on improved rotor designs, testing of machines in utility grids, design contracts for large turbine components, and data collection at candidate sites for future machine field tests across the U.S.[10]

Contracts for the 200 kW test turbine were awarded to supply rotor blades and to install machines at Clayton, New Mexico, and at Culebra, Puerto Rico. The Clayton installation and checkout were completed, and first operation was accomplished in November 1977.

General Electric completed machine design of a 2 MW turbine, and procurement of components was initiated. Operation will commence in November 1978, on a mountaintop near Boone, North Carolina. The Boeing Corp. was selected as the contractor to design and install one or more "second generation" 2.5 MW turbines.

Installation of meteorological towers at 17 candidate sites was completed, and data are being obtained for all sites. A mobile data system for monitoring startup of wind turbines at all different sites was procured.

Kaman Aerospace was selected to design and fabricate a 45 m composite rotor blade. Urethane and prestressed concrete blade studies were also completed, and a wooden rotor blade study contract was awarded.

The 17 m vertical-axis Darrieus wind turbine was installed in March 1977 at the Sandia Albuquerque Laboratory and tested in a 2-bladed configuration. Its performance[11] (both structurally and from a power output standpoint) was excellent and agreed with prior analyses. A low-cost Darrieus turbine fabrication program was initiated. This program called for redesign of the 17 m system by a commercial organization to introduce as many cost-saving processes as possible. An RFP was issued and four responses received. A parametric optimization of the Darrieus turbine study was initiated to identify the most cost-effective configurations and sizes. During FY78, the 17 m turbine will be tested in a 3-bladed configuration, and a contract for low-cost commercial fabrication of the Darrieus turbine will be awarded.

The goals of the Small Wind Energy Conversion systems (SWECS) program are to stimulate manufacture and sales, increase public use, and reduce the cost of energy from WTGs.[12] Energy costs can be reduced by decreasing WTG capital cost, improving performance, increasing reliability, or extending equipment lifetime.

A Test Center was established and a total of eight different WTGS mounted on towers for testing. At year end, five were undergoing tests, two had been returned to the manufacturers for retrofit of design improvements, and one had been destroyed in a windstorm. Specific design improvements were identified and implemented on two WTGs as a direct result of testing.

Technology development subtasks for small wind machines were begun for development of 1 kW High-Reliability, 8 kW and 40 kW WTGs. Two contracts were announced for 8 kW WTG development (with Windworks, Inc., of Mukwanago, Wisconsin, and United Technologies Research Center of East Hartford, Connecticut). Two contracts will also be awarded for the 1 kW and 40 kW size turbines. The 40 kW machines have a goal of $500/kW (including tower but excluding installation); the 8 kW WTGS have a goal of $750/kW. The High-Reliability WTGs have as a primary goal the capability of operating unattended for one year in a severe environment and a secondary cost goal of $1500/kW.

Efforts in standards development resulted in an informal survey of the wind energy community's opinions. The American Wind Energy Association (AWEA), with assistance from Rockwell International and DOE, will pursue establishment of standards for small WTG performance evaluation.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

The Federal wind program has grown rapidly in funding since 1973. These funds have been used to initiate a wide variety of studies. The rapid growth in funding does not mean, however, that additional funds are not necessary or could not be productively used. Also, the great diversity of the present R&D effort does not mean that the different areas of study are now treated as equally important or that the optimum method of coordinating the many separate tasks has been found.

The greatest importance in the present program is given to providing utility-grid power from propeller-type machines of the largest possible physical size. The sizes of these proposed machines approach real limits determined by manufacturing and economic factors.[13] For example the largest machine planned will have blades 45 m in radius. Rail transport from a manufacturing center to a field installation is limited to 53 m sections, and the largest standard heavy construction cranes are 61 m tall. Thus, transportation and field assembly would be much more costly if even larger sizes were attempted.

Extensive plans exist for field tests of horizontal-axis prototypes at different sites (and hence climatic conditions) across the United States. Similar plans exist to evaluate the performance of small machines (less than 100 kW) of different types and then to test them under ocean, desert, or other conditions. No comparable plans exist to test large versions of the Darrieus vertical-axis machines. Uncertainty also exists regarding the comparative performance of large Darrieus and propeller machines when placed in an identical wind environment.

Production of utility power is considerably more difficult to evaluate than are nonutility applications. Utility grids are required to provide power on demand even if an intermittent power source is used and also must have very exact control of electrical voltage and frequency. Providing this control restricts options available to the designer and makes optimum conversion of the wind to other energy forms more difficult. Synchronization with the grid frequency can be easily accomplished if wind turbines do not contribute more than 10% of the local system power. Above this level the stability (stable frequency) of the system may be reduced, and more complex utility engineering problems occur.

The utility companies also face a complex economic situation. The cost of generating electricity varies greatly during the day because different fuel and equipment are used to meet the changing hour-by-hour demands for power. The wind is intermittent and cannot guarantee power at a given hour when the most expensive "peak load" power is generated. Thus, previous economic studies have largely concentrated on using wind energy for long-term fossil fuel savings or compared wind energy to inexpensive base-load power costs. The cost of conventional fuels are now a "pass-through" cost to consumers in many cases. Saving fossil fuels, although important nationally, has a reduced economic importance to utilities under these conditions.

The value of wind energy for electric utility purposes, therefore, is a complex issue, involving daily and seasonal power demands, fuel costs, rate structures, and the "mix" of existing (or future) equipment available for power generation. The value of wind energy locally used as a direct substitute for other energy forms can be more easily determined. Applications exist where the energy "storage" is the "product," e.g., irrigation or process heat. Wind energy also offers a wide range of power levels, from a few kilowatts to several megawatts, and can provide heat, mechanical power, or electricity. It is a versatile energy source not inherently limited to any one type or scale of application.

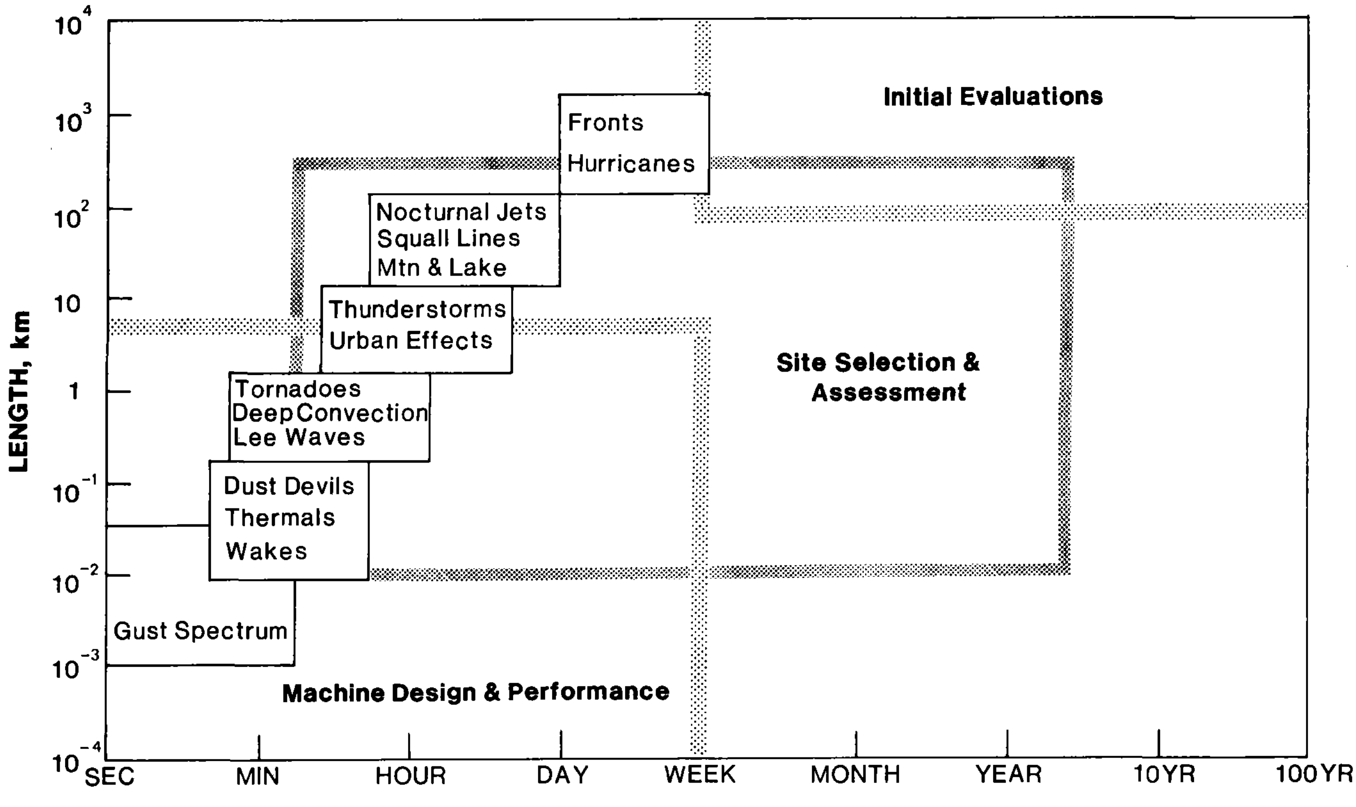
The optimum size for individual wind turbines is unclear. Greater effort on relatively small turbines began in FY77 and will be accelerated in FY78, as a result of the Rockwell International/Rocky Flats program. Early studies predicted that the lowest costs would occur for very large machines with power ratings of a few megawatts. The potential importance of small wind machines, acording to *Science* magazine,[14] has not been thoroughly assessed. Intermediate size machines with power ratings of approximately 100-1000 kW would be useful in distributed energy systems or in clusters for heating and cooling, pumping fluids, and community generation of electricity. It has been suggested that the market for such applications, measured in total power delivered or in fossil fuel saved, might be comparable to large machines in centralized electric power generation.

All recent cost projections assume lower future costs due to mass production. To achieve the same power delivery, more small machines are required, and the potential for lower manufacturing costs may be greater. The small and intermediate turbines are close to the scale of other industrial goods that have shown economies in mass production. The largest proposed turbines are larger than jumbo jets, which are produced in limited quantities. Thus, the optimum turbine sizes and applications for the economic use of wind energy are yet to be determined.

Standards regarding wind turbine safety and performance are inadequate at present, and building codes do not cover these products. Product liability insurance will be difficult or impossible to purchase until "zones of safety" surrounding a machine can be clearly defined. Support has been given for a Federal initiative to define standards that would be modified to suit each state. Equipment warranties, specifications, and safety standards are also important considerations in consumers' tax credits or other incentives.

Regardless of the turbine design or size, the energy delivered by a wind system will depend on where the system is sited. Predicting the output of existing (or future) machines across the United States cannot be done with certainty now. The output of a machine depends on the mean wind speed *and* on variations about the mean. Thus, identical machines placed in two different parts of the nation with equal mean wind speeds may produce different outputs. At any location, the energy output will also vary with time—from one year to the next, by season of the year, by day, and by hour within the day. This is true because many weather phenomena occur over distances or time periods important to wind energy collection (Figure 13-1).

Figure 13-1. THE TIME AND SPACE SCALES IMPORTANT TO WIND ENERGY DEVELOPMENT



Source: Hardy and Walton, "Wind Energy Assessment," presented at Miami International Conference on Alternative Energy Sources, Dec. 1977.

Assessment of the wind resource is vital and complex. In any region of the United States, the available wind energy will change with time. Energy needs also are time dependent. The match between the two will be important. Other solar resources will also be locally available. The wind must therefore be compared with other solar options, and an optimum choice or combination of solar technologies selected. The best choice will not be the same for each region of the nation.

Notes

[1]Frank R. Eldridge, *Wind Machines*, The MITRE Corporation for the National Science Foundation (Grant AER-75-12937), October 1975.

[2]Volta Torrey, *Wind Catchers* (Brattleboro, Vt.: The Stephen Greene Press. 1976).

[3]Eldridge, *Wind Machines* (1975).

[4]M.R. Gustavson, *Wind Energy Resource Parameters,* M77-29, The MITRE Corporation, METREK Division, February 1977.

[5]*Summary Report, Federal Wind Energy Program*, ERDA-77-32, Energy Research and Development Administration, 1977.

[6]Personal communication, L. Divone, Wind Systems Branch of the Department of Energy to D. Hardy, Solar Energy Research Institute, January 1978.

[7]*Proceedings*: The Third Biennial Conference and Workshop on Wind Energy Conversion Systems, September 19-21, 1977, ERDA sponsored, published by JBF Scientific Corporation.

[8]Ugo A. Coty, *Wind Energy Mission Analysis*, SAN/1075-76/1, Lockheed California Company for the Energy Research and Development Administration (Contract No. AT (04-3)-1075, Sept. 1976. Also John A. Garate, *Wind Energy Mission Analysis*, COO/2578-1/1, General Electric Space Division for the Energy Research and Development Administration (Contract No. EY-76-C-02)2578), February 1977.

[9]C.E. Elderkin and J.V. Ramsdell, *Annual Report of the Wind Characteristics Program Element for the Period April 1976 Through June 1977*, BNWL-2220 WIND-10, Battelle Pacific Northwest Laboratories for the Energy Research and Development Administration (Contract No. EY-76-C-06-1830), July 1977.

[10]Personal communication, W. Robbins, NASA-Lewis Program Office, to D. Hardy, Solar Energy Research Institute, January 1978.

[11]Personal communication, R. Braasch, Sandia Albuquerque Program Office, to D. Hardy, Solar Energy Research Institute, January 1978.

[12]Personal communication, T. Healy, Rocky Flats Program Office, to D. Hardy, Solar Energy Research Institute, January 1978.

[13]*Proceedings*: Wind Energy Conversion Systems (1977).

[14]William D. Metz, "Wind Energy: Large 'and Small Systems Competing," *Science*, Vol. 197, September 2, 1977, pp. 971-973.

14. OCEAN THERMAL ENERGY CONVERSION (OTEC)

BASIC TECHNICAL DESCRIPTION

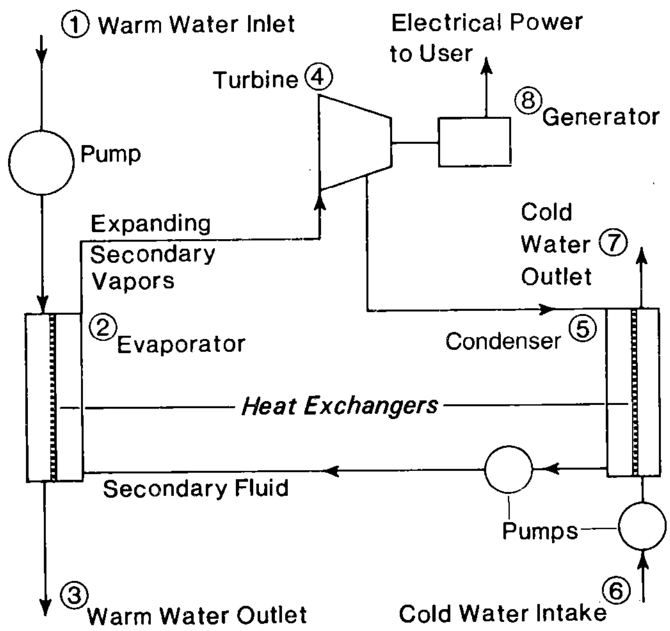
Ocean thermal energy conversion (OTEC) is an indirect form of solar energy application. OTEC uses the thermal gradient which exists in tropical ocean zones between warm surface water and colder water at depths of 1000 m. The available resource has a 40°F temperature difference in the best case and 36°-38°F on the average. This gradient can drop to as low as 30°F during the winter months or during times of severe storms. OTEC R&D is now being pursued at three levels: engineering development in closed-cycle equipment; exploratory research in an open-cycle approach; and feasibility studies of the "foam and mist" cycle. Each is discussed below.

Closed-Cycle Technology

An OTEC closed-cycle plant converts the ocean thermal energy gradient using the cycle illustrated in Figure 14-1. Warm surface water is pumped into the plant and enters a heat exchanger used to evaporate a working fluid. In the current engineering program this fluid is ammonia, but propane, freon, and others have been considered. The heat exchanger must operate in contact with sea water on one side and with the evaporating working fluid on the other, maintaining a high coefficient of heat transfer in the face of corrosion and biofouling threats on the sea water side. The vapor created is expanded through a turbine and condensed in another sea water heat exchanger, returning to the evaporator by way of the condensate pump. Cool ocean water required for this condensation is drawn from the ocean depths through a long pipe. Since the temperature difference is low, there is a very low pressure difference across the turbine, and therefore a very low conversion efficiency to mechanical energy (3%). The expansion turbine in this cycle is usually coupled to a conventional electrical generator, but mechanical shaft power could be the preferred output.

In 1973 and 1974, system studies on this basic scheme were produced by Carnegie-Mellon University and the University of Massachusetts.[1] Their work was reviewed and greatly extended in 1975 by the Lockheed Missile and Space Company and the TRW Systems Group.[2] The latter proposed designs which were in the range of 100-160 MW capacity using modular designs in the range of 25-40 MW. In spite of some variation in the details of the systems, the more conservative analyses showed the ratio of gross power to net power was on the order of 1.6 to 1.0. This reflects a substantial

Figure 14-1. SCHEMATIC DIAGRAM OF A CLOSED-CYCLE OCEAN THERMAL POWER PLANT



Source: H. Gary Knight, et al., *Ocean Thermal Energy Conversion* (Lexington, Mass.: Lexington Books, D.C. Heath & Co., 1977).

mount of parasitic auxiliary pump power required to circulate the sea water for both heat exchangers. Also, the net output of the plant could go toward zero under detrimental off-design conditions.

The most expensive hardware subsystems in the proposed closed-cycle OTEC plants are the heat exchangers. One proposed design recommends titanium tubing in order to avoid the corrosion problems inherent with alternative materials. The amount of titanium required for a 160 MW (100 MW net) plant is 17.6 million pounds.[3] By comparison the total U.S. production of titanium tubing in 1974 was 2.9 million pounds. This explains the heavy OTEC program emphasis on aluminum heat exchangers.

A second major hardware is the turbine power plant. All OTEC advocates have proposed using hardware which is a modest extension of the low-pressure steam turbines used in current power plants. The third hardware system, the sea water pumping system required for a 100 MW plant, is larger than anything which has ever been built for operation in the ocean. However, it reflects a fairly minor technological innovation: either larger versions of existing hardware can be developed, or current types of equipment can be linked in parallel.

The platform is a fourth major subsystem in an OTEC plant and offers several significant structural challenges.

First, the hull design must withstand the effects of storms and waves and other environmental hazards. Second, the cold water pipe must reach to ocean depths of 1100 m; there are unique problems of deployment and structure load resulting from forces between the pipe and the hull. Third, the mooring of the platform, in depths on the order of 6100 m presents a major problem. This has been dealt with to a certain extent in large buoys, but positioning for periods of much over three years has not been proven. Closely related to the mooring question is a fifth major subsystem—the power transmission cable connecting the generating station is the user facility. The problems here are the method for accommodating the ocean, and the cost of the cable itself.

A major issue raised by the futher development of the OTEC concept is cost-effectiveness. The most recent system cost estimates were compiled by Curto[4] and are in the range of $948-$2394/kW, or $0.02-$0.035/kWh. There is little doubt that the OTEC equipment can deliver useful power. The challenge of the program is to verify these highly encouraging estimates.

Open-Cycle Technology

The earliest demonstration of the OTEC concept was an open-cycle approach, accomplished by Claude on the coast of Cuba in 1930. The concept uses sea water as the working fluid, thus eliminating the need for both of the heat exchangers employed in the closed-cycle approach. However, this also requires that the pressure over the boiling water be reduced to the vapor pressure of water at the input temperature, in this case approximately ½ psi (about $^1/_{30}$ atmosphere). The elimination of the heat exchangers is somewhat offset by the added costs of (1) an evacuated chamber, (2) extremely large turbomachinery (because of the high specific volume of the working gas), and (3) air removal from the working fluid. However, recent studies indicate that this trade-off is possible, and that the open-cycle approach can be competitive in terms of dollars per kilowatt capacity. Initial feasibility studies have been completed, and an engineering design program is now underway to more accurately size the equipment.

Foam or Mist Cycle

A subset of the open-cycle concept is an approach which eliminates the need for the large turbine required in the open-cycle. In this approach, liquid water is entrapped and lifted in a vapor stream or within a foam structure. This foam can be created through the use of detergent or the natural foaming action of sea water. The liquid in the vapor stream, or in the foam, is lifted to a height sufficient to drive a hydraulic turbine. This approach is in an early feasibility study stage and cannot yet be considered a viable alternative to the other OTEC approaches.

FEDERAL PROGRAM GOALS

The Federal OTEC effort is aimed at constructing by 1985 an ocean thermal plant which is able to demonstrate economic feasibility by:

- demonstrating heat exchange performance in the face of corrosion and biofouling conditions;
- developing a hull configuration and system structural characteristics compatible with the ocean environment;
- establishing a design which incorporates materials, proceses, and an operating environment which are economically competitive;
- developing a product mix and distribution system which can be competitive in the marketplace;
- identifying the financial, legal, and institutional infrastructure which would promote commercialization of the technology.

Table 14-1. FEDERAL OTEC PROGRAM FUNDING FOR FY77[5]

Program Support	$ 2.38 M
Definition and System Planning	2.02 M
Engineering Developments	1.92 M
Engineering Test and Evaluation	1.50 M
Advanced R&D	5.76 M
Total	$13.58 M

Source: Note 5

PRINCIPAL DEVELOPMENTS IN FY77

- A testing program for corrosion and biofouling was established, and low biofouling rates were measured.
- The multitube heat exchanger test facility at Argonne National Laboratories began operations.
- Enhanced heat exchange performance was demonstrated in single tube models.
- Detailed cost estimates for the first sea-based test facility (conversion of the Hughes mining barge) were completed and will form the basis for planning construction of such a facility.
- Design studies for the first commercial demonstration unit were initiated. These include:
  * platform studies (including cold water pipe, hill, and mooring system);

* power module design;

* power transmission cable studies.

ADVANTAGES

Use of OTEC for power production has some advantages.

- OTEC is one of the few solar technologies with base load capacity.
- Many potential sites for OTEC plants already suffer from high energy costs.
- Power production could be combined with mariculture since OTEC systems regurgitate nutrient-rich deep water into shallow, more productive depths.
- OTEC is a possible energy source for energy-intensive processes such as aluminum smelting or ammonia production.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Unknowns regarding OTEC technology include:

- corrosion resistance;
- biofouling susceptibility and removal;
- structural integrity, especially during major storms;
- cost estimates;
- mooring capability;
- legal issues (Law of the Sea);
- possible release of large amounts of CO_2;
- possible changes in ocean surface temperature with undetermined results.

Notes

[1]C. Zener, et al., *CMV Progress Report,* NSF/RANN/SE/GI-39114/PR/74/1, April 30, 1974 and W. E. Heronemus, et al. University of Massachusetts Report, NSF/RANN/SE/GI-34979/PR74/1, April 30, 1974.

[2]Lockheed Missiles and Space Company Inc., Ocean Systems, *Ocean Thermal Energy Conversion (OTEC) Power Plant Technical and Economic Feasibility,* Vols. 1 and 2, LMSC-0056566, April 12, 1975 and TRW System Group, *Ocean Thermal Energy Conversion,* Vols. 1-5, Final Report, (June 1975).

[3]H. Gary Knight, et al., *Ocean Thermal Energy Conversion,* (Lexington Books: Lexington, Mass., 1977).

[4]Paul Curto and Grant Miller, "An Update on OTEC Baseline Design Costs," 5th OTEC Conference, Miami, Fla., 1978.

Also: A.D. Watt, et al., *Open Cycle Ocean Thermal Energy Conversion–A Preliminary Engineering Evaluation,* Report ALO/3723-76/3, December, 1977.

[5]Personal Communication, Sigmund Gronich, Branch Chief, ERDA Oceans Systems to B. Shelpuk, SERI, Dec. 29, 1977.

15. SOLAR POWER SATELLITE

INTRODUCTION

Solar Power Satellite (SPS) systems are being proposed to deliver baseload elecltric utility power from space. The concept employs a satellite in orbit and one or more associated power receiving stations on the ground. Power would be transferred by high-precision microwave beams; typically 5000 MW to 10,000 MW would be transmitted in a beam. The source of energy is the Sun, with either photovoltaic or thermal engine conversion in the satellite. Several alternative approaches are possible, including the use of nuclear reactors, materials delivered from the Moon instead of the Earth, and reflection of solar radiation to ground stations.

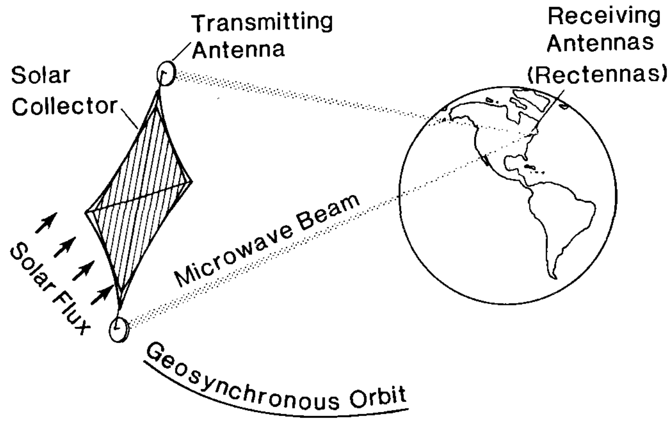
BASIC TECHNICAL DESCRIPTION

The SPS concept generally combines six major components:

- transportation system (launch vehicle, tug to geosynchronous orbit, personnel launching, and interorbit transfer);
- ground launch complex;
- manned geostationary orbiting facilities;
- energy conversion;
- microwave transmission; and
- Earth receiving antenna, rectifier to DC electricity (rectenna), and utility interface.

Technical variations include solar thermal-electric conversion, solar photo-electric conversion, nuclear energy conversion, orbiting reflectors, and use of nonterrestrial materials. (See Figure 15-1.)

Figure 15-1. MAJOR ELEMENTS OF A SOLAR SATELLITE POWER STATION



Source: ERDA 76-148, November 1976.

Photoelectric Solar Energy Satellite (PSES)

Several methods of photoelecltric conversion to electricity are under study. Two promising approaches are silicon solar cells and gallium arsenide solar cells. Microwave transmission is used for energy transmission to earth. Costs ranging from $2100/kW[1] to $5600/kW[2] have been estimated.

Solar Thermal-Electric Energy Satellite (STES)

An STES in geostationary orbit (GSO) concentrates solar radiation on an absorber by means of large mirror arrays. The thermal energy thus produced would heat a gas to run a Brayton-cycle thermal engine. Electricity is then transmitted to Earth via microwave transmission. An example of this approach is Boeing's Powerset system to use solar energy to heat helium and power turbo-generators. A recent study estimated costs of $2540/kW for the STES.[3]

Nuclear Power Satellite System (NPSS)

Nuclear reactors have also been considered as the energy source in an SPS. in this concept, reactor modules would be assembled and fueled in low orbit and transported to GSO. Molten salt and gas core reactors are possible. Both would employ recycling of fuel material in order that no nuclear materials would ever be returned to earth. Magnetohydrodynamic generators as well as Thermionic and Brayton cycles have been studied. The remaining elements of the

SPS system are the same as the solar SPS. A 1972 cost estimate of a pilot plant by the Atomic Energy Commission was $1000/kW,[4] but more recent estimates are not available. Major questions exist about public acceptance of orbiting of nuclear materials and the difficulty and cost of recycling nuclear fuel materials in orbit.

Orbiting Reflectors for Terrestrial Power

This concept is based on the use of orbiting mirrors to reflect sunlight to a ground station. Very lightweight, metal-coated polymeric films would first be deployed at 800 km and then placed in operational orbit (1400 km to 10,000 km). One preliminary study indicates that mirrors in space may be more cost-effective than on the ground. Costs of electricity are estimated as $0.01 to 0.025/kWh[5] with CdS solar cells on the ground and somewhat higher for a solar thermal engine on the ground. A brief review of this concept led some researchers[6] to believe that the energy cost with solar thermal or silicon photovoltaic conversion on the ground would probably be more than $0.10/kWh.

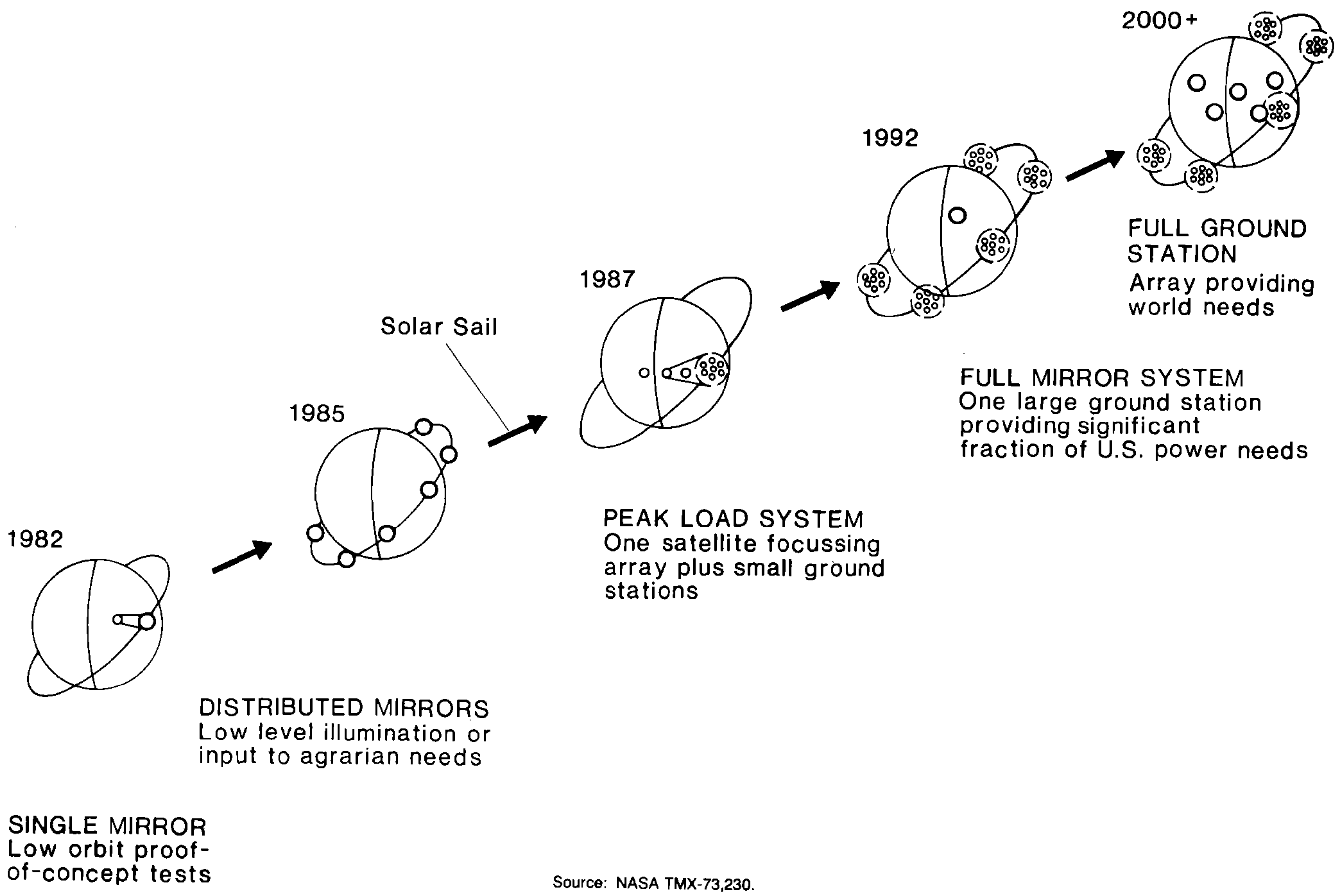
The key advantage of this concept is the low cost of the satellite and transportation system; a heavy lift vehicle is not required. Development costs are much less than for other SPS concepts since full scale demonstration could be accomplished with the current space shuttle. The concept is presently in a very early stage of investigation. Key questions are performance, cost, satellite life, and environmental impacts. Possible developmental stages for an orbiting reflector are shown in Figure 15.2.

Use of Nonterrestrial Materials

In this concept, materials from the Moon or from asteroids would be to construct the SPS. A space colony would operate a space manufacturing facility to build the SPS. The primary advantage is low-propulsion energy required to lift materials off of the Moon.

The concept for power generation and transmission is the same as the other SPSs. However, the nonterrestrial concept does not need a new Earth-to-space transportation system. It does require a space colony at the L-5 equilibrium point (a point of neutral gravity between the Earth and Moon) and a mining base on the Moon. In addition, a new type of propulsion system must be developed and demonstrated to deliver ore from the Moon to the space colony. The overall development program is estimated to cost $40-$60 billion,[7] which includes the cost of developing a 6-mile by 20-mile colony. Proponents state that twenty 10,000 MW power stations could be on line in the 1990s.

Figure 15-2. POSSIBLE DEVELOPMENT STAGES FOR AN ORBITING REFLECTOR SPS

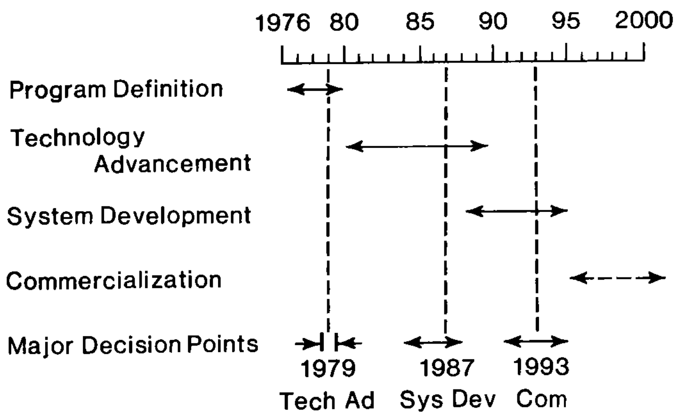


Source: NASA TMX-73,230.

DESCRIPTION OF THE FEDERAL PROGRAM

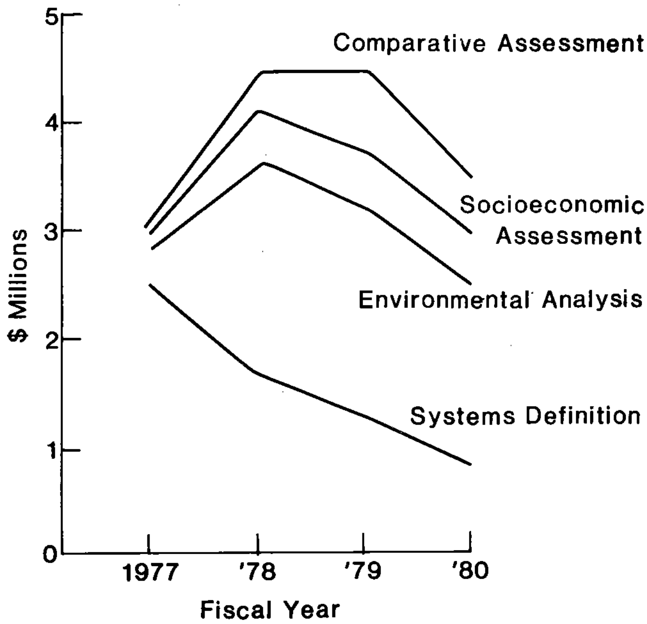
DOE shares responsibility with NASA for the overall satellite power system program, which is divided into four phases as shown in Figure 15-3.

Figure 15-3. SPS DECISION DEVELOPMENT STAGES



Source: ERDA 76-148, November 1976.

Figure 15-4. SPS BUDGET BY SUBPROGRAM ELEMENTS



Source: ""DOE Program Management Status Review-Solar Power Satellite."

The current phase is addressing five principal questions or issues which have to be resolved satisfactorily before engineering development can be undertaken. These issues are, in order of priority:

- Are the environmental impacts roadblocks to developing SPS?
- Could SPS be economically viable?
- Are the institutional, political, and legal impacts of SPS roadblocks to its development?
- Are there major technical design uncertainties?
- Are there logistical and operational concerns that would render the SPS concept impractical?

Environmental analysis, socioeconomic assessment, and comparative assessment are DOE's responsibility. NASA will perform system definition studies in support of the program. The planned budgets for the current phase are shown in Figure 15-4.

PRINCIPAL DEVELOPMENTS IN FY77

- ERDA and NASA agreed upon an SPS policy paper. DOE now has management responsibility for the program with NASA support on the systems definition task.
- An ERDA/NASA concept development and evaluation program plan was prepared.
- Parallel system definition activities were initiated at NASA Johnson Spacecraft Center (The Boeing Company as contractor) and NASA Marshall Spacecraft Center (Rockwell International as contractor).
- NASA conducted internal concept evaluation studies and assessments of the required technology advancements.
- An initial comparative assessment of orbital photovoltaic to ground solar, advanced fossil, and nuclear energy systems was completed at the NASA Jet Propulsion Laboratory. An Orbital Impacts and Benefits study is also in progress at JPL.
- An introductory assessment of orbiting reflectors was prepared by NASA Ames Research Center.
- Supportive technology development in large space structures and space stations is continuing at NASA.
- Several contracts on alternative concepts for the SPS were initiated.

ADVANTAGES OF THE SPS

The SPS System offers the following advantages:

- no need for the storage systems required with most other proposed solar systems;
- reduces the need for long distance transmission lines if microwave rectennas can be located near load centers;
- can be used all over the world, independent of the prevailing weather conditions;

- excess heat burden on the biosphere is minimized, but similar to terrestrial solar thermal-electlric systems.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Large improvements in the current state-of-the-art of all SPS components are required. Various impacts exist at each stage of development of the SPS energy system. Key issues which must be resolved are summarized below:

Transportation

The SPS requires development of a second-generation space transport system. DOE's transport cost target is one-tenth that of the NASA space shuttle[8] or about $145/kg of payload delivered to geosynchronous orbit.[9] To justify the enormous developmental cost of the transport systems, a firm commitment to many SPSs first must be made. Transport for one 5 GW satellite would require 50 to 500 flights of a new heavy-lift launch vehicle larger than the Saturn V.[10] The transport system introduces chemical pollutants at all levels in the atmosphere. The environmental and health impacts must be carefully evaluated as well as the noise pollution of both the launch and re-entry systems. Station-keeping propulsion at geosynchronous orbit will probably introduce ionized particles into the magnetosphere with unknown effects.

Solar Arrays

One study indicates that an SPS with output power between 3-15 GW is optimal in terms of performance weight.[11] To produce this much power at 15% solar cell efficiency and 67% microwave transmission efficiency, 35-70 km^2 of solar cells are necessary.[12] Solar cells, however, are not yet 15% efficient. Improvements in solar cell efficiency, weight, durability, and especially cost must occur. The SPS cost goal is a cost reduction 25 to 65 times below the current costs for terrestrial silicon cells and is similar to DOE's silicon cost goals. But this must be for a space-qualified cell which is much lighter than a terrestrial cell with better efficiency (25% greater) and resistance to radiation damage.[13]

Microwave Transmission

A 10 GW SPS might employ two 5 GW microwave transmitters.[14] Each microwave transmitter would have to be about 1 km in diameter in order to concentrate a beam which would radiate onto a terrestrial receiver of about 11 km in diameter and an area of 75 km^2 (30 mi^2) each. Depending on permitted levels of microwave radiation exposure, the required land area may be as high as 300 km^2 (120 mi^2) for each 5 GW.[15] The receiving antennas could be installed on land or water at latitudes less than 60°. However, the biological effects of microwave radiation are largely unknown, as are the environmental effects on the atmosphere. There are potential problems with radio-frequency communications interference and possibly radio astronomy interference. Microwave transmission also needs efficiency improvements.

Economic Viability

One of the overriding issues confronting SPS development is economic viability. Cost targets for the transport shuttle, solar cells, microwave subsystem, and other components may be out of reach for many years. If those cost targets are achieved, other constraints, such as resource availability, may take hold. Problems of low net-energy efficiency and short system lifetimes may also exist.

The large Federal RD&D investment ($50-$100 billion)[16] leading to the first SPS and the long time period for development (about 20 years), present problems in decisionmaking, risk, and payback.

Other Problems

- The receiver land area requirement of 300 km^2 per 5 GW is based on microwave radiation levels of 0.10 MW/cm^2 at the plant boundary. This is 1/100 of the current U.S. standard for continuous exposure to microwave radiation, but it is 10 times the current Eastern European standard. If the Eastern European standard is used, the required plant land area would triple to 900 km^2 (350 mi^2) per 5 GW plant.[17] (This is a square 59 miles on a side). Overlapping of the side lobes of adjacent microwave beams may lead to substantial increases in land requirements beyond 900 km^2 per 5 GW. Public perception of safety and acceptability of locating the microwave beam receiver near populated load centers may restrict location of the rectennas to remote areas.

- The SPS appears susceptible to military attack, sabotage, and blackmail. This could complicate polictical dealings with foreign governments or terrorist groups. The SPS also has military potential. This may affect SPS design or require international cooperation in designing, building, operating, and possibly owning the SPSs.

- Launch aborts of these heavy lift vehicles which might affect human safety is a low-probability/high-impact event typical of nuclear reactors.

- Use of the limited resource of geosynchronous orbit locations and interference with global communication frequencies will require international resolution.

Notes

[1]J. Mackoviak, "A Systems Engineering Overview of the Satellite Power Station," Grumman Aerospace Corporation.

[2]Richard Caputo, "An Initial Comparative Assessment of Orbital and Terrestrial Central Power Systems, Final Report," Jet Propulsion Laboratory 900-780, March 1977.

[3]W.J. Grimes, "Feasibility and Engineering Studies of Solar Energy Transmission Satellites," (Berlin, F.R. Germany: Algemme Elektricitacts-Gasellschaft AEG Teletunken, May 1975. The approach used by Caputo leads to an estimated cost closer to $5000/kW$_e$.

[4]"Hearings before the Joint Committee on Atomic Energy—AEC Authorizing Legislation," U.S. Congress, 92nd Session, Part 2, March 1971.

[5]Kenneth W. Billman, William P. Gilbreath, and Stuart W. Bower, "Introductory Assessment of Orbiting Reflectors for Terrestrial Power Generation," NASA Technical Memorandum NASA TMX-73230, April 1977, p. 39.

[6]T. Fujita and R. Caputo, Orbital Reflector Review at JPL, May 11-13, 1977.

[7]Brian O'Leary, "The Construction of Satellite Solar Power Stations from Nonterrestrial Materials," *Journal of Energy*, Vol. I, No. 3, May-June 1973, pp. 155-158.

[8]Energy Research and Development Administration, *Final Report of the ERDA Task Group on Satellite Power Stations*, ERDA 76-148, November 1976, p. 9.

[9]"An Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts," Lyndon B. Johnson Space Center, August 1976.

[10]Caputo, "Orbital and Terrestrial Central Power Systems" (March 1977).

[11]Grimes, "Studies of Solar Energy Transmission Satellites" (May 1977).

[12]Ibid.

[13]Caputo, "Orbiting and Terrestrial Central Power Systems" (March 1977).

[14]Ibid.

[15]"Evaluation of Space Solar Power Concepts," Lyndon B. Johnson Space Cendter (August 1976).

[16]Caputo, "Orbital and Terrestrial Central Power Systems" (March 1977).

[17]Ibid.

16. BIOMASS ENERGY

BASIC TECHNICAL DESCRIPTION

The Sun, falling on the 2 billion acres of the United States, generates about 30 Quads per year of stored solar energy in the form of biomass, equivalent to about 40% of the total national energy consumption. (See Table 16-1.) Biomass is the generic term for the material produced by this photosynthesis in all forms (wood, corn cob, algae, etc.). In many ways, biomass is an environmentally attractive fuel. It is low in sulfur and ash compared to coal. The effect of biomass energy harvesting on atmospheric CO_2 will be small relative to fossil fuel burning. Biomass can be produced indefinitely, with slight modification of our present farm and forest practices. A century ago, about 2.4 Quads of wood were harvested for fuel from the Eastern forests of the United States. We are now

Table 16-1. BIOMASS ENERGY POTENTIAL FOR UNITED STATES[1]

Category	Quads/Yr.		Quads	Estimated Cost $/MBtu
Present Biomass Growth [a]				
Cultivated Crops (350 M Acres)	14			
Forest Growth (500 M Acres)	10			
Forage Grass (700 M Acres)	3.5			
Total:	27.5			
Present Residues	[b]	[c]		
Municipal Waste	2.2	1.0		0-2
Agricultural	5.1	1.5		2-3
Forest	1.9	1.6		1-3
Sewage	0.1	0.2		2-5
Manures	3.4	0.4		2-5
Total:	8.4	4.7		
Stored Biomass [d]				
Land Improvement [e]			16-160	1-3
Biomass Mines [f]			10	2-3
Total:			25-170	
Steady State Energy Farms				
Land [g]	12-64			1-4
Aquatic [h]	?			?
Total:	>20			

Source: DOE/ET-0022/1, p. 4.

turning again to the use of biomass in all forms for energy and must determine how much we can practically collect or produce and what solid, liquid, and gaseous fuels we wish to make from this clean, renewable form of solar energy.

Production of Biomass Fuel

Potential biomass sources can be broken down into five categories. They range from existing residues such as agricultural, forest, and municipal wastes, to aquatic biomas, such as algae and kelp. These categories are shown in Table 16-1; estimates are made of the current total resources or the potential total resource if available land were used for this purpose. Of this total energy, only a limited amount is collectible, within a reasonable level of difficulty, and estimates are also shown in Table 16-1. The estimated cost of fuel derived from these various sources ranges from \$0-\$5/MBtu.

The cheapest and most attractive, presently available forms of biomass are the agricultural, forest, and municipal residues we now generate (shown in Table 16-1). Although we generate about 8.4 Quads of these residues, it is estimated that we might economically collect 2-5 Quads. In many cases, these residues pose a disposal problem, and have a "negative cost"; in other cases, there will be a cost of collection, but they are available now at costs from \$0-\$5/MBtu, some in the form of a gas composed largely of methane.

A second category that has been relatively well studied is the biomass that could be produced on "energy farms"—land devoted to harvesting of high-yield plants such as sorghum or fast rotation hardwoods such as sycamore, with projected annual yields of 20 and 8 tons/acre respectively. These energy crops could be grown on land of marginal use, of which 100-200 million acres have been identified in the United States, and thus would not interfere with production of crops and forest products. These lands could produce 12-64 Quads/yr. The biomass would probably be converted to electric power, methane, or ammonia, using existing technology.

This year the Department of Energy Fuels from Biomass Branch has completed three major studies of raising sugar crops, fast rotation forestry, and grains and grasses. These studies have shown that it is possible to greatly increase the yields from forest and field by using selected species and improved techniques. Several test plants are now being planned to put these ideas to the test.

The "energy farm" concept also could be extended to growth of aquatic plants in lakes or oceans. Plants such as algae, water hyacinth, or giant kelp could be grown, harvested, and converted to methane by anaerobic digestion.

A fourth category can be termed "land improvement residues." During the settlement of this country, a great deal of land has been disturbed and has grown over with scrub and other transition species of no particular value. Other large acreages are covered with dead or diseased trees. The cost of clearing this land makes land improvement impossible unless there is a fuel value for the biomass removed (generally in chip form) during replanting. These lands will carry 10-50 tons of biomass per acre. If a commodity market in biomass fuels existed, say at \$20/ton or \$1.25/MBtu, land clearing would generate \$200-\$1000/acre in revenue to support the work. The land could be turned into farms, forests, or "energy farms," depending on its best use. The exact number of acres which could be improved is not presently known, but it is large compared to that available for energy farms—perhaps 100-200 million acres and yielding 16-160 Quads.

Finally, a number of "biomass mines" have been created in the United States over the past decades. Best recognized at present are the land fills, some of which are being studied as sources of methane gas. The forest industries and food-processing industries have created enormous mounds of bark, sawdust, peapods, coffee grounds, etc., during their operations over the years. These are very large potential sources of energy and could make these industries energy-independent for many years. They can be used to generate methane "in situ," or gasified to produce process heat. The removal of these residues would generally be considered valuable. Again, the exact quantities are not known, and methods of using these "biomass mines" are only beginning to be studied.

Conversion of Biomass to Other Energy Forms

Much biomass has long been available but has not been used as an energy source. The basic problem is to find economical methods for harvesing and processing biomass into more useful forms. The "thermoconversion" processes use high temperatures to convert biomass to energy. The simplest of these is combustion to make steam or electricity. The forest industries generate about 1.0 Quad of energy in this fashion, and sugar mills and some municipalities obtain power from biomass. As oil and gas become more scarce, this option appears more attractive, and studies are underway at the Department of Energy examining the establishment of dedicated energy farms on land supporting a central power station. One plant being studied for Lincoln, Maine, may produce 50 MW from wood chips transported up to 50 miles from the surrounding forests.

In general, biomass as harvested is too wet to burn and too bulky to ship. Some interesting processes are now being developed to produce "densified biomass fuels"—pellets, cubes, or briquettes of biomass which are more easily shipped, stored, and burned than is the initial form. These denser forms have been called "instant coal" because they can be shipped and burned much like coal. Plants processing 300 tons/day cost typically \$1 million and add about \$0.50/MBtu to the fuel cost. These processes use 10-15% of the energy in the biomass for processing.

Unfortunately, the simple combustion of biomass requires new equipment designed for biomass (or coal) combustion since the majority of our present industry uses gas- or oil-fied boilers which cannot handle solid fuels. However, these plants can be converted to biomass fuels by using a "gasifier."

A gasifier uses partial combustion with air to oxygen to generate a gas containing carbon monoxide and hydrogen. This gas, in turn, is suitable for combustion in existing plants without solids-handling equipment. Several companies are now manufacturing air gasifiers in the 1-10 MBtu/hr range, and others are developing larger equipment. Several plants in the United States are now operating on this "wood-gas," generated from wood chips.

It is also possible to use oxygen to gasify biomass. This has several advantages to offset the cost of the oxygen. An oxygen gasifier has been developed—the Union Carbide Purox gasifier—which converts 300 tons/day of municipal waste into a 300 Btu/SCF fuel gas that is known as "synthesis gas." This gas costs $2-5/MBtu and can be used directly in power stations. A pyrolysis plant funded by DOE at Texas Tech makes medium Btu gas from manure. This gas may also have some promise for chemical synthesis.

In addition to generating electricity, biomass can be converted into valuable gaseous or liquid fuels. For example, the synthesis gas from gasified biomass can be used to make methanol, ammonia, methane, or even gasoline.

Other processes, using microorganisms, are available for conversion of biomass to the higher grade liquid or gaseous fuels. These are called "bioconversion" processes. In 1938, the countries of Europe used 150 million gallons of alcohol mixed with gasoline for motor fuel. This alcohol was produced by fermentation from sugar beets, corn, wheat, potatoes, and even wood. Brazil has begun construction of 15 alcohol plants to use sugar from cane or starch from cassava. Tests in Nebraska show a number of advantages of "gasohol" over gasoline, including improved mileage, higher octane, and lower emissons. A bill has been passed by Congress authorizing $60 million in loan guarantees for construction of four demonstration alcohol plants in the United States and to provide research money for improving alcohol production.

When a slurry of biomass (manures, sewage, etc.) is acted upon in the absence of air (anaerobic digestion), the gas methane is produced. This is particularly attractive as a source of energy on farms and feedlots where there is a high production of manure (40 pounds per cow per day) which would otherwise be a disposal problem. The sludge remaining after digestion is an excellent fertilizer; the solid residue can be used as a high protein feed supplement. This process has long been used in Asia, and is being sold now in the United States. A large experimental gas producer funded by DOE is now being constructed at a feedlot in Florida.

DESCRIPTION OF THE FEDERAL PROGRAM

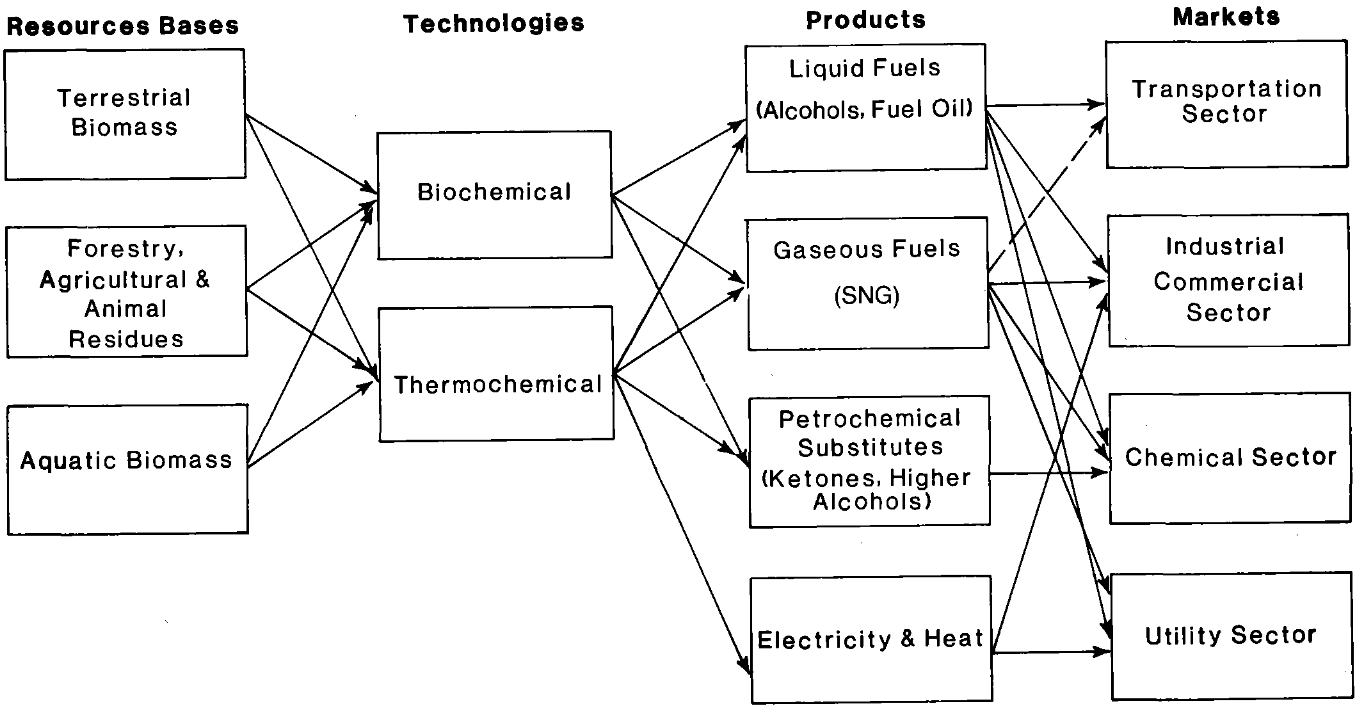
The overall objective of the Fuels From Biomass (FFB) program is the development of the capability to convert renewable biomass resources into clean fuels, petrochemical substitutes, and other energy-intensive products that can supplement similar products made from conventional fossil fuels. The FFB program focuses on the generation and conversion of terrestrial and aquatic plant materials, including forest and crop residues, crops grown on energy farms, and animal manures. The program does not include conversion of industrial or municipal solid wastes.[2]

The Fuels From Biomass research and development efforts concentrate on:[3]

- growing terrestrial and aquatic crops on energy farms;
- harvesting, collecting, transporting, and storing biomass;
- converting biomass to fuels and petrochemical substitutes.

The FFB program overview (Figure 16-1) lists the four major sources of biomass and some of the processes by which they can be converted to energy-intensive products.[4]

Figure 16-1. FUELS FROM BIOMASS PROGRAM OVERVIEW



Key milestones anticipated during FY78 are:[5]

- the completion of the construction of an anaerobic digestion pilot plant;
- initiation of the preliminary design of a prototype thermochemical conversion (gasification) reactor;
- completion of testing for a prototype harvester for small-diameter, closely spaced trees;
- completion of systems studies for aquatic biomass production and harvesting;
- initiation of testing for a preliminary design aquatic harvester.

Funding distributions and the historical Federal funding levels for the Fuels From Biomass program are shown respectively in Tables 16-2 and 16-3.

Current Research and Development Objectives of the Fuels From Biomass Program by Program Element and Subelement[6]

- Agricultural Production—to optimize agricultural production to provide maximum energy at a minimum cost from this biomass source.
- Silvicultural Production—to grow and harvest woody plants which will provide maximum energy content at minimum costs.
- Residue Production—to develop processes to use field crop residues, animal manures, and forest and mill residues as a source of biomass.
- Aquatic Production—to improve production yield, growth, nutrient assimilation, fermentability, and economic feasibility of aquatic biomass.

Table 16-2. PRIMARY BIOMASS FUNDING DISTRIBUTION (Percent)

Program Element	Other Federal Agencies	National Laboratories	Universities	Small Business Contractors	Other Contractors
Production of Biomass	18.4	14.9	39.8	8.9	18.0
Conversion of Biomass	0.1		50.0	9.9	40.0

Source: DOE/ET-0022/1, p. 31.

Table 16-3. BIOMASS PROGRAM ELEMENTS AND FUNDING ($1000)[1]

PROGRAM ELEMENTS	FY 1975	FY 1976/TQ[2]	FY 1977	FY 1978
Production and Collection of Biomass	$569	$1,431/451	$3,069	$6,720
Conversion of Biomass				
Anaerobic Digestion		1,084/30	1,634	1,200
Fermentation		189/455	1,370	$3,460
Biophotolysis and Photoelectrolysis			386	400
Thermochemical Conversion		1,730/1396	2,872	7,375
Miscellaneous and Support	33	158/21	537	1,085
TOTALS	$602	4,592/2,353	9,868	20,240

[1] Obligations
[2] FY 1976 & Transition Quarter (July-Sept. 1976)

Source: DOE/ET-0022/1, p. 32.

Conversion to Biomass

- Anaerobic Digestion—to develop processes for the production of methane from treated biomass.

- Fermentation—to develop methods to enhance hydrolysis, to to develop enzyme systems, to optimize processes for ethanol production, and to investigate other fermentation processes.

- Biophotolysis—to develop processes that offer the potential of producing clean hydrogen fuel from water.

- Thermochemical Conversion—to develop thermal and chemical processes for cost-effective conversion of biomass to energy.

- Photoelectrolysis—to develop processes for the decomposition of water by catalyzed, solar energy-driven means to produce hydrogen.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

Biomass, mostly in the form of wood, was the principal fuel in the United States until about 1900, when it was replaced by coal. Biomass is already returning as a fuel, but its use will increase only slowly relative to the most convenient energy forms unless stimulated in various ways.

The first barrier against acceptance of biomass fuel is that it cannot be used in existing equipment. Tax incentives will make it possible to convert existing equipment to biomass (e.g., using gasifiers) or to install new equipment. In cases where the equipment has not yet been fully developed it will be necessary to construct demonstration plants to determine costs and improve operation for commercial acceptance.

There are a number of ways in which cost comparisons can be misleading and make biomass seem less economical than it is. Present energy forms, such as gas and oil, are highly subsidized in exploration and production, so that the true cost of domestic oil, for instance, may be $25/bbl ($4/MBtu) when these subsidies are taken into account.

On this basis, many of the biomass energy forms in Table 16-1 are already competitive. A second subsidy of fossil fuels is the environmental subsidy. When our production of fossil fuels was small, it was convenient to assume that the environmental damage of mining, drilling, and burning them was negligible. Now that we have escalated the use of these fuels, we know the hidden price we pay in terms of acid rain (SO_2 from coal), land damage from strip mining, oil spills near our coasts, nuclear waste disposal problems, and ultimately, possible weather change resulting from increased CO_2 in the atmosphere. Although we cannot easily put a dollar price on these costs, we know they are heavy.

Finally, a third cost which must be evaluated in deciding what new energy forms to use is the social and political cost associated with importing 50% of our oil and increasing amounts of natural gas from other countries. It has been estimated that $1.00 spent in the United States produces $1.80 in benefit to this country compared to $1.00 spent overseas.

Thus, when we take all these factors into account, we see that other energy forms may cost two, four or even eight times as much as the "price" at the wellhead, shipping terminal, or mine. Biomass energy, on the other hand, has no hidden subsidies; it can be environmentally beneficial (if practiced with suitable controls); it is socially beneficial to the United States and could put many unemployed to work.

There are some environmental concerns about harvesting biomass on a large scale, and these are well founded. There are many desert areas on Earth where forests once grew—the result of unrestrained exploitation. Yet, we also know that humans have produced food and wood on a continuing basis for thousands of years when they have taken proper precautions.

Therefore, any large scale biomass energy program would require controls to make sure that the biomass will be produced on a continuing basis. For instance regulations could be established to insure that trees being cut were replaced at an equal or greater rate. A tax on biomass fuel could yield funds for research into the long-range effects of biomass farming and for regulation to continually improve the productivity of the land and the oceans. In this way, the United States and the world can operate on their renewable resources of sunlight, water, and land, rather than operating on the capital of stored and mined energy.

Notes

[1]This table shows the magnitudes of energies now or potentially available in the United States through collection of sunlight by conversion to biomass. Some estimates are necessarily more speculative than others and in many cases are very open-ended, depending on many factors. The figures are based on many sources. The following notes explain the significance of the various entries.

a) Total biomass now produced on the 350 M acres of U.S. fields (assuming an average of 2.5 tons/acre-year) the 500 M acres of commercial forest land (assuming 1.25 tons/acre-year) and the 700 M acres of grassland (assuming 0.31 tons/acre-year).

b) Residues now produced.

c) "Easily collected" residues.

d) Stored biomass available once only.

e) Assumes 100-200 M acres of land improved with standing crops of 10-50 tons/acre.

f) Assumes 5% of the dry residues produced in (a) over last 20 years are recoverable from landfill, barkpiles, food process dumps, etc.

g) Assume 100-200 M acres of land converted to raising biomass crops with 8-20 tons/acre yield.

h) Aquatic farming with presently undeveloped techniques difficult to specify, but available area very large.

See Also: R.E. Inman, *Silverculture Biomass Farms–Vol. I, Summary*, MITRE Corporation, Technical Report 7347, May 1977.

E.S. Lipinsky, et al., *System Study of Fuels from Sugar Cane, Sweet Sorghum, and Sugar Beets, Volume I–Comprehensive Evaluation*, Battelle Columbus Laboratories, BMI-1977, March 15, 1976.

R. Benson, *Biomass Potential from Agricultural Production*, Conference Proceedings, Biomass—A Cash Crop for the Future, Midwest Research Institute and Battelle Columbus Laboratoies, Kansas City, Mo., March 1977.

J.R. Benemann, *Biofuels: A Survey of Potential and Prospects*, Electric Power Research Institute Report, December 15, 1977.

J.A. Alich, et al., *An Evaluation of the Use of Agricultural Residues as an Energy Feedstock–A Ten Site Survey, Vol. I–Summary and General Information*, Stanford Research Institute, July 1977.

National Academy of Sciences, *Renewable Resources for Industrial Materials*, A report of the Committee on Renewable Resources for Industrial Materials (CORRIM) Board on Agriculture and Renewable Resources Commission on Natural Resources National Research Council, National Academy of Sciences, Washington, D.C., 1976.

[2]"Fuels From Biomass Program," *Draft* Program Summary, DOE/ET-0022/1, U.S. Department of Energy, Division of Solar Technology, January 1978, p. 2.

[3]Ibid., p. 6.

[4]Ibid., p. 2.

[5]Ibid., p. 26.

[6]Ibid., pp. 35-46.

17. PHOTOCONVERSION TO ELECTRICITY AND FUELS

BASIC TECHNICAL DESCRIPTION

Photoconversion includes those biological and chemical conversion processes which are initiated by the excitation of specific molecules by light. Photoelectrochemistry also is included under photoconversion because chemical reactions are involved. Photoconversion differs from thermochemical conversion because an increase in temperature does not necessarily accompany absorption of light; it differs from photovoltaic conversion in that processes are involved other than those associated with solid state phenomena. The products of photoconversion of solar energy can be fuels, chemicals, or electricity.

Photoconversion can be divided into two general areas: Photobiology and Photochemistry.

Photobiological Processes

Photobiological processes encompass both modified photosynthetic and nonphotosynthetic processes. Green plants normally fix carbon and produce biomass. If normal photosynthesis is modified by subjecting whole organisms such as algae to abnormal environmental conditions, by modifying the organism genetically, or by using extracted components of the photosynthetic apparatus, fuels such as hydrogen or electricity can be produced. Conversion efficiencies much higher than the 0.1% to 2% values observed for the production of biomass in the field may well be possible. About 15 U.S. groups, in addition to a number of groups in Japan, the United Kingdom, Germany, Israel and the U.S.S.R. are working on various aspects of photobiological conversion of solar energy. Other photobiological energy conversion processes, such as those observed in the "purple membrane system" of *H. halobium*, also have been suggested as potential candidates for solar applications.

Photochemical Processes

Photochemical processes can be carried out in either homogeneous and heterogeneous systems. Homogeneous systems generally refer to liquid solutions in which direct or photosensitized chemical reactions occur. Photosensitization is a process in which light energy is absorbed by one molecule and then transferred to another, more reactive molecule. Examples of direct photochemical reaction are dissociation and synthesis. These are diagrammed in Figure 17-1.

Figure 17-1. EXAMPLES OF DIRECT PHOTOCHEMICAL REACTIONS

Dissociation:

$$AB \xrightarrow{\text{light}} AB^*$$
$$AB^* \longrightarrow A + B$$

Synthesis:

$$C \xrightarrow{\text{light}} C^*$$
$$C^* + D \longrightarrow CD$$

Starred species represent high-energy, excited, electronic states of the molecule.

Heterogeneous systems refer to suspension or immersion of insoluble materials in aqueous solution. Examples of these are "model systems" (which, in one configuration, might mimic photosynthesis through nonbiological processes) and photoelectrochemical cells. Again, solar-generated fuels such as hydrogen, storable chemicals, and electricity are potential products.

DESCRIPTION OF THE FEDERAL PROGRAM

The implicit goals of photoconversion research are to:

- develop basic knowledge in the areas of photobiology and photochemistry;
- identify specific photoconversion and related processes which might be used in solar energy conversion applica-ions;
- determine the energy conversion efficiencies of promising processes;
- characterize the hardware which photoconversion devices might require.

Elements of a photoconversion program can be found in various parts of DOE, including the Office of the Assistant Secretary for Energy Technology, Office of Energy Research, and the Division of Biomedical and Environmental Research, with support also being provided by DOD and NSF. For the most part, funding is at the basic research level since applications are currently limited by a lack of knowledge of basic biological and photochemical processes. Table 17-1 contains an estimate of expenditures for photoconversion in FY77 and FY78:

Table 17-1. AN ESTIMATE OF PRESENT FUNDING LEVELS IN PHOTOCONVERSION

	FY77 ($M)	FY78 ($M)
Fuels from Biomass Program (ET)*	0.39	0.40
Division of Basic Energy Sciences (ER)**	3.44	4.15
Division of Biomedical and Environmental Research***	?	0.50
NSF****	0.42	?
DOD	?	?

*Program Summary, Fuels from Biomass Systems Branch, September 1977.
**Program Summary, Division of Chemical Sciences, Solar-Related Research, November 1977.
***Program Summary, Division of Biomedical and Environmental Research, 1978.
****Computer search of NSF grants.

PRINCIPAL DEVELOPMENTS IN FY77

It is difficult to pinpoint important developments on a year-to-year basis because so much of the work is exploratory in nature. It sometimes takes years to determine what single discovery will have significant impact in an application area. With that caveat, recent important events include production of hydrogen in multi-organism systems,[1] isolation of mutant organism with a hydrogenase (an enzyme) that has some degree of oxygen tolerance,[2] production of electricity from isolated photosynthetic membranes,[3] progress in immobilizing the hydrogenase enzyme,[4] improvement in the conversion efficiency of photoelectrochemical cells,[5] and production of hydrogen and electricity in synthetic photochemical systems.[6]

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

David O. Hall has said, "The development of photobiological energy conversion systems has long-term implications from both energy and food points of view."[7] Prior to his death in 1976, Gabriel Stein reflected, "In principle, it now appears that some photochemical devices may in the near future become competitive with dry photovoltaic devices, which themselves are already marketable."[8] In spite of this optimism, much more exploratory and basic research must be funded and implemented. Restriction of funds solely to projects which might lead to practical devices in the near term would be myopic and foolish. Any attempt to limit scientific thought to narrowly defined areas would be counterproductive both in the near and long term. Furthermore, people with diverse backgrounds should be brought into the area of photoconversion, and interdisciplinary approaches must be encouraged.

Uncertainties in the area of photoconversion of solar energy stem from the fact that the discipline is still quite young, and the technology, undeveloped. Scientists are still trying to understand basic photobiological and photochemical processes which might be applicable in solar conversion devices, while concurrently attempting to build such devices. Technical problems abound—improvements in stability, reliability, conversion efficiency, and product collection must be addressed before cost reduction and scale-up problems.

It is unrealistic to expect technical demonstration of economic photoconversion processes before the 1985 to 1995 period, or any significant impact on the U.S. energy system before 2000 to 2020.

Notes

[1] H.H. Weetall, Presentation at the session on Uses of Negative Potential Generated by Photobiological Processes at the Conference on Biotechnology of Electron Transport Processes, University of Pennsylvania, November 5-9, 1977.

[2] A.C. McBride, S. Lien, R.K. Togasaske, and A. San Pietro, "Mutational Analysis of *Chlamydomonas reinhardi*: Applications to Biological Solar Energy Conversion," in a. Mitsui, S. Miyachi, A. San Pietro, and S. Tamuar (eds.), *Biological Solar Energy Conversion* (New York: Academic Press, 1977), p.271.

[3] M.J. Allen, "Direct Conversion of Radiant into Electrical Energy Using Plant Systems," in R. Buvet (ed.), *Living Systems as Energy Converters* (Amsterdam: Elsevier/North Holland Biomedical Press, 1977), p. 271.

[4] T.J. Deloggio and D.J. Graves, "The Kinetics and Thermodynamics of Hydrogen Production Using Immobilized Hydrogen," in *Proceedings*: The 2nd Pacific Chemical Engineering Congress, New York, American Institute of Chemical Engineers (AIChE) Press, 1977, p. 791.

[5] K.C. Chang, A. Heller, B. Schwartz, S. Menezes, and B. Miller, "Stable Semiconductor Liquid Junction Cell with 9 Percent Solar-to-Electrical Conversion Efficiency," *Science*, 196:1097, 1977.

[6] F.K. Fong, "Far Red Photogalvanic Splitting of Water by Chlorophyll *a* Dihydrate," *Journal of the American Chemical Society*, Vol. 99, 5802, 1977; F. Kampas and J. Fajer, "Photoelectrochemical Properties of Porphyrins, Chlorins, and Bacteriochlorins," in *Proceedings*: The 13th Informal Photochemistry Conference, Clearwater Beach, Florida, January 4-7, 1978.

[7] D.O. Hall, "Will Photosynthesis Solve the Energy Problem?", in J.R. Bolton (ed.), *Solar Power and Fuels* (New York: Academic Press, 1977), p. 45.

[8] G. Stein, "Photochemical Conversion and Storage of Solar Energy," in Bolton, *Solar Power and Fuels*, p. 23.

18. THERMOCHEMICAL CONVERSION TO ELECTRICITY AND GASEOUS, LIQUID, AND SOLID FUELS

BASIC TECHNICAL DESCRIPTION

Thermochemical conversion schemes are processes in which solar *heat* drives chemical reactions to produce electricity, fuels, or stored chemical energy. Three types of conversion processes are currently receiving attention: thermochemical dissociation, reversible chemical reactions, and solar-electro-chemical conversion.

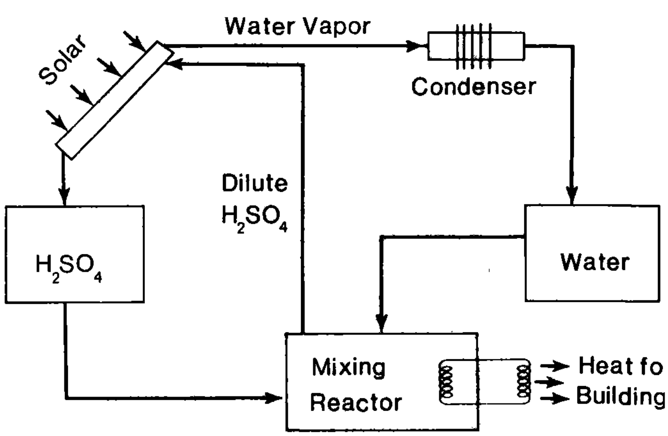
Thermochemical Dissociation

Thermochemical dissociation, the use of heat to break down chemical substances, is being applied to produce hydrogen fuel. In these schemes, solar heat would drive chemical reactions in closed cycles, the net result of which is the dissociation of water to hydrogen and oxygen. Analogous schemes could conceivably involve fixing atmospheric nitrogen to a chemical fertilizer or breaking down carbon dioxide to carbon monoxide which would be used as a fuel.

Reversible Chemical Reactions

Reversible chemical reactions in simple systems permit storage and transport of high-grade energy. These devices, sometimes called chemical heat pipes, capture solar energy by using it to create high-energy molecules which can be transported, stored, and then reacted to release the heat at another place or another time. One scheme being studied by DOE[1] is illustrated in Figure 18-1.

Figure 18-1. DOE/THERMAL STORAGE AND TRANSPORT PROGRAM– CHEMICAL HEAT PUMP STORAGE



Average Size 1 to 10MW. Cycling Daily.

Source: G. Pezdirtz, DOE.

Solar-Electrochemical Conversion

A third type of thermochemical conversion involves heat-driven chemical reactions followed by conversion to electricity in battery or fuel cell devices. Such devices can be thought of as thermally rechargeable batteries or as electrochemical heat engines.

GOALS AND DESCRIPTION OF CURRENT PROGRAM

No programs which specifically fall in this category received funding in FY77 under DOE sponsorship.

The thermochemical programs within DOE were developed in response to the problem of transporting or storing nuclear heat from fission reactors. Most of the work had been supported by the Division of Conservation in ERDA, with significant basic support from the Division of Physical Research (now Basic Energy Sciences in DOE). There are significant research efforts worldwide on both H_2 production from water and reversible chemical reactions for storage, but, again, mostly in the context of transporting and storing nuclear heat.

Domestic programs are funded at several million dollars per year; worldwide efforts are reported to be larger, particularly in Germany,[2] Italy,[3] and Japan,[4]

It has been suggested recently that solar heat sources may be better matched to driving thermochemical reactions than are nuclear sources.[5] (Some cycles being considered may require temperatures of 1150 K.) Attention may be shifted to solar sources, partly because of the uncertain future of nuclear power.

Solar-electrochemical conversion appears to be the approach receiving the least investment currently. Only a few basic studies are being funded in the DOE program.

PRINCIPAL DEVELOPMENTS IN FY77

Because of the basic exploratory nature of solar thermochemical research, principal developments in any one year are hard to define. For the solar program, the most significant development is the increasing inclusion of solar energy among the heat sources being considered.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

The solar-thermochemical conversion area appears to suffer from both lack of identification and lack of support in the DOE energy program. In the area of thermochemical conversion of sunlight to fuels and electricity, more exploratory and basic research needs to be carried out. This research should be relevant to solar conversion, though much more basic work at the university level should be supported. Many chemical processes remain to be identified, as well as tested for technical and economic feasibility. Perhaps the highest priority should be that suggested by Von Hippel and Williams in a recent article entitled, "Toward a Solar Civilization": "The best approach may be to let a thousand flowers bloom, and then cultivate the most promising varieties."[6]

Notes

[1]Program supported by the Division of Energy Storage Systems, Office of Energy Technology, DOE.

[2]Julich Nuclear Research Center, West Germany.

[3]Euratom Joint Research Center in Ispra.

[4]See for example, T. Ohta et al., *Int. J. Hydrogen Energy, 1,* 113, 1976.

[5]M.G. Bowman, "Thermochemical Production of Hydrogen from Water," Los Alamos Scientific Laboratory, Report #LA-UP77-1337, 1977.

[6]F. Von Hippel and R.H. Williams, *Bull. of the Atomic Scientists, 33,* 12, 1977.

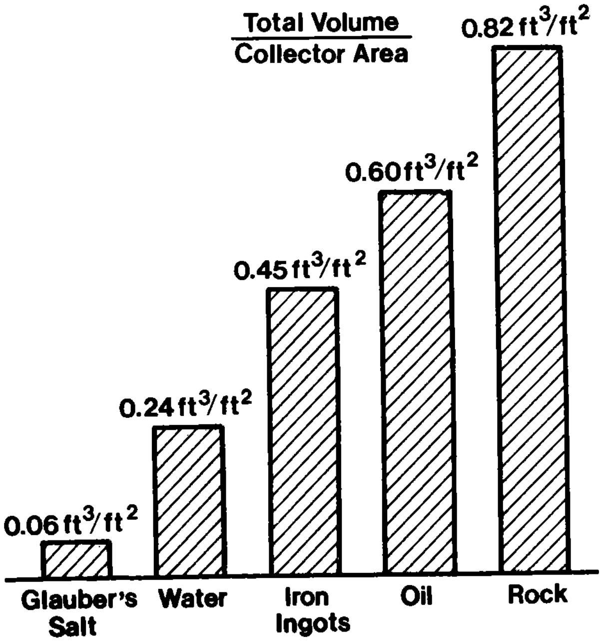
19. THERMAL STORAGE

BASIC TECHNICAL DESCRIPTION

"Thermal storage" usually refers to placing thermal heat (i.e., from a solar collector) into some medium for later withdrawal and use. (See Tables 19-1 and 19-2; Figures 19-1 and 19-2.) However, thermal energy storage also includes the storage of cooled media, as well as thermal energy conversion into chemical forms for later reconversion. Storage concepts being developed have capacities from a few hours to several months. In every case, thermal storage can act as an invaluable buffer when solar energy supply is out of phase with demand, whether due to regular daily variation, periods of cloudy weather, or the annual seasonal changes.

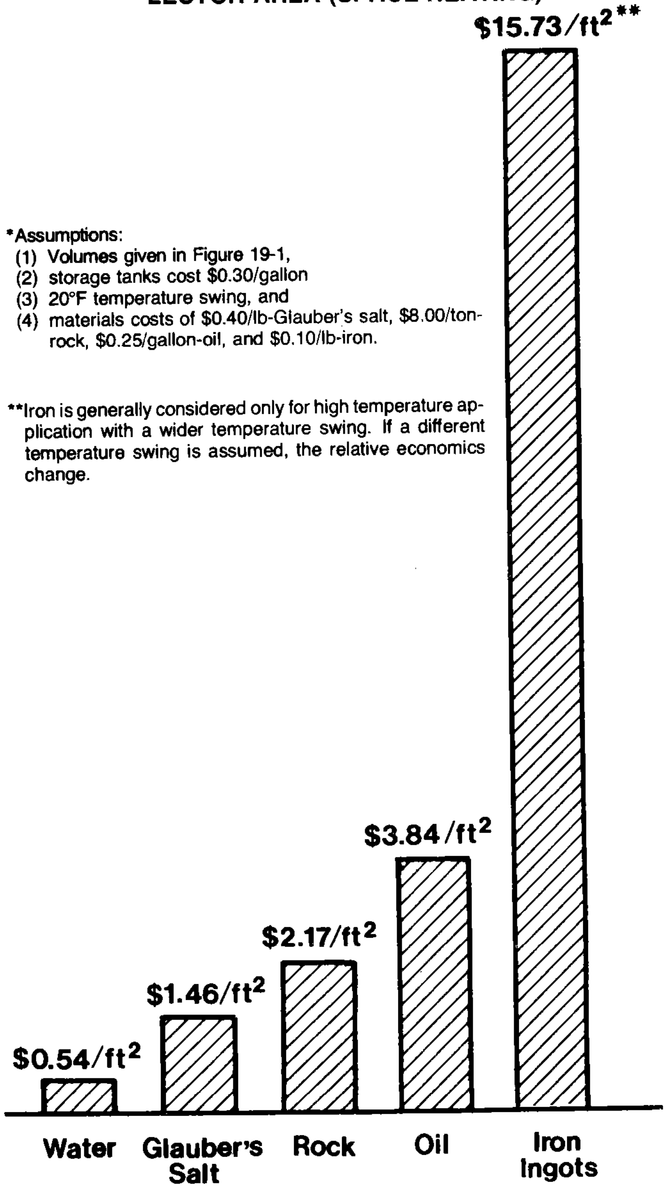
The four general types of storage systems under development are sensible heat, phase change, reversible chemical reactions, and seasonal.

Figure 19-1. VOLUME REQUIRED FOR VARIOUS STORAGE MEDIA (SPACE HEATING)*



*Based on information and assumptions in Table 19-1 and Figure 19-2.

Figure 19-2. ESTIMATED COST OF VARIOUS STORAGE MATERIALS PER SQUARE FOOT OF COLLECTOR AREA (SPACE HEATING)*



*Assumptions:
(1) Volumes given in Figure 19-1,
(2) storage tanks cost $0.30/gallon
(3) 20°F temperature swing, and
(4) materials costs of $0.40/lb-Glauber's salt, $8.00/ton-rock, $0.25/gallon-oil, and $0.10/lb-iron.

**Iron is generally considered only for high temperature application with a wider temperature swing. If a different temperature swing is assumed, the relative economics change.

Sensible Heat Storage

All materials have "thermal capacitance": energy transferred to a material causes an increase in temperature of the material. Water can store large amounts of thermal energy for a moderate temperature rise (1 calorie per gram per degree C). Rocks and other inorganic materials have a heat capacity only one-fifth that of water, but their greater density partly compensates for that. Most low-temperature solar systems employ either hot water or hot rock storage for heating systems. The Löf solar house in Denver, Colorado, has been operating for the past 20 years using the hot rock system.

A convenient rule of thumb for estimating the amount of storage required for home heating systems is 75 liters of water, or ¼ m^3 of rock, for each square meter of collector area.

Table 19-1. HEAT CAPACITY OF THERMAL ENERGY STORAGE MATERIALS

	Per Unit Weight cal/g-°C	Per Unit Total Volume cal/cm^3-°C
Water	1.0	1.00
Oil	0.5	0.40
Rock	0.2	0.30
Iron	0.1	0.55

Table 19-2. POSSIBLE REVERSIBLE CHEMICAL REACTIONS FOR STORAGE

Reaction			Heat Generated or Absorbed
$Ca(OH)^2$	$\rightleftharpoons$	$CaO+H^2O$	23 kcal
$2SO^3$	$\rightleftharpoons$	$2SO^2+O^2$	48 kcal
CH^4+H^2O	$\rightleftharpoons$	$3H^2+CO$	49 kcal

Phase-Change Heat Storage

When materials change from the solid phase to the liquid phase, they absorb large quantities of heat at their melting points. The same amount of heat is released when the material freezes. Glauber's salt, studied by Dr. Maria Telkes for several years, is being marketed as a phase-change storage material under the trade name "Solar-Aire" system. Closely related to the phase-change process is the adsorption-desorption of liquid on solid, gas on solid, or gas in liquid. The adsorption process is accompanied by release of heat; the reverse process, desorption, consumes the same amount of heat. The chief advantages of phase-change over sensible heat are the smaller storage requirements and the relatively constant temperature.

Reversible Chemical Reactions

For high-temperature applications or uses where solar collection is remote from the user, reversible chemical reactions offer promise for both energy storage and transport. If solar heat is used to decompose ammonia into hydrogen and nitrogen, then the same amount of energy can be recovered upon recombination of the gases to produce ammonia. In this example, energy storage and transportation are accomplished by storing and transporting the hydrogen and nitrogen. A group in Germany is developing a similar process called EVA+ADAM which uses the reaction between hydrogen and carbon monoxide to produce methane and water. While the intent in Germany is to use *nuclear reactor* heat to decompose the methane, Scott Lynn of the Lawrence Berkeley Laboratories is investigating the use of *solar energy* for heat.

Seasonal Storage

In addition to the chemical reaction approach, a promising long-term storage concept is to use confined aquifers (water-bearing strata of permeable rock, sand, or gravel) to store either hot water or chilled water. Warman at Auburn University is testing the seasonal storage of hot water; Davison of Texas A&M is testing chilled water storage in confined aquifers. Yuan of George Washington University is investigating the technique of using the ground itself for long-term storage of solar heat for space and hot water heating. Another interesting storage concept for balancing the seasonal cyclic heating and cooling loads of a building, being developed by Oak Ridge National Laboratory, is the Annual Cycle Energy System (ACES). During the winter, a tank of water supplies heat to a water-to-air heat pump for heating; the ice produced by the heat pump is stored to provide air-conditioning in the summer.

In 1963 in Israel, Tabor demonstrated seasonal storage possibilities using solar ponds. Thermal losses were greatly reduced by the addition of salt, which naturally traps higher temperatures at deeper levels, as a result of higher salinity concentrations. Ted Taylor of Princeton recently has proposed a similar concept using inflatable plastic covers to reduce evaporation and nighttime cooling. Amory Lovins has reported on several existing, highly energy-conserving structures which use large water tanks for residential seasonal storage. One large advantage for home heating by these seasonal approaches is the ability to use the collector during the summer and fall and thereby reduce the required area of solar collector.

DESCRIPTION OF FEDERAL THERMAL STORAGE PROGRAM

Goals of the DOE Thermal Storage program are to:

- complete a prototype diurnal, heating and cooling, solar energy storage system by 1981;
- complete exploratory development of a solar energy storage system for thermal electric power generation by 1981;
- complete prototype development of a seasonal, heating and cooling, aquifer storage system by 1982.[1]

The federal programs in solar energy storage are integrated with other, more general programs in storage, such as industrial waste heat utilization, and load-leveling storage of nighttime heat from nuclear reactors. All thermal storage programs are administered by four different groups within DOE—the Division of Energy Storage

Systems (most of the funds and projects are administered here), Division of Solar Technology, Division of Solar Applications, and the Conservation Division. The FY78 budget for solar-related thermal storage projects is about $5 million with over 30 separate projects funded.[2]

PRINCIPAL DEVELOPMENTS IN FY77

- Seventy percent energy recovery from hot water storage in aquifer was demonstrated.
- A mathematical model of hot water storage in aquifers was validated.
- Subscale prototype of sulfuric acid/water chemical heat pipe was constructed.
- Technical feasibility of a high-density polyethylene phase-change material with stable shape was demonstrated.
- Feasibility of incorporating phase-change materials in building material was demonstrated.
- Preliminary cost of seasonal storage for solar thermal power systems was shown promising.
- Comprehensive compilation of candidate reversible chemical reactions was completed.
- Glauber's salt was successfully cycled 1000 times.

Advantages of Using Storage Systems

- Short-term storage enables greater use of solar energy as a buffer between supply and demand.
- Seasonal storage enables an increased use of solar energy on a year-round basis.
- Chemical reaction storage enables energy transport over long distances.
- All storage systems are energy-conserving (i.e., fuel-displacing) techniques.
- There are potential economies whenever and wherever other backup fuel costs are high.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

- All forms of storage are presently expensive.
- Performance data are lacking
- Reliability data are lacking.
- Most systems require further R&D.
- Safety may be a problem for some systems.
- The need for short-term storage is uncertain when a lower cost backup system is available.
- Insufficient funds have been devoted to the storage program.
- Coordination among the four DOE sponsoring groups may be inadequate.
- Storage system design may not be optimally matched with the existing electrical utility systems.
- Present storage programs do not address intermediate temperature storage (100-300°C).

Notes

[1]George F. Pezdirtz, "Energy Storage and Solar Energy-Future Scenarios," oral presentation, Solar Energy Research Institute: Golden, Colo. (January 3, 1978).

[2]C. J. Swet, "DOE Thermal Energy Storage Programs," oral presentation, Solar Energy Research Institute: Golden, Colo. (December 14, 1977).

20. ELECTROCHEMICAL AND MECHANICAL STORAGE

BASIC TECHNICAL DESCRIPTION

Electrical Storage

Batteries directly convert electrical to stored chemical energy through reversible chemical reactions. (See Table 20-1.) The cells in a battery provide direct current and consist of positive and negative electrodes in electrical contact through an electrolyte medium. Cells may be self-contained as with commercial lead-acid and nickel-cadmium systems or may be comprised of separate storage and electrode (power) capability with a pumped electrolyte as with zinc-chlorine and redox batteries.

Because of the modular nature of batteries, potential applications exist in all scales of stationary use as well as in electrical vehicle propulsion (Figure 20-1).

Mechanical Storage

Mechanical storage refers to storing energy in the form of potential or kinetic energy. (See Table 20-2.)

Flywheels and Inertial Systems (Figure 20-2) store kinetic energy in objects (conventionally discs) fabricated from high strength metals or composites, and spun to high angular velocities. The stored energy density is limited by the rotational speed and thus by the cohesive strength and defect density of the flywheel material. Efficiency is determined primarily by the coupling to the primary power source and the bearing losses of the flywheel.

Aboveground Pumped Hydrostorage (Figure 20-3) is the only economical mode of large scale energy storage now available to utilities. It operates like conventional hydroelectric power generation except that to operate the turbines the water must first be pumped up-hill by using electricity generated by off-peak system capacity. This application is primarily suitable for utility load-leveling applications. A proposal to integrate a large scale wind system with the pumped hydroelectric potential of Western rivers been made by the Bureau of Reclamation.[1]

Underground Pumped Hydrostorage (Figure 20-4) is similar to aboveground pumped storage with one or both reservoirs located below ground surface level to permit a greater number of siting options and reduce the area requirements for aboveground installations. Although primarily a largescale storage system, underground systems could be adapted to commercial and neighborhood use.

Underground Compressed Air Storage (Figure 20-5) is primarily for utility applications. This approach stores off-peak energy in the form of compressed air in large, underground, airtight reservoirs. The compressed air can be stored in a constant volume or (using hydrostatic techniques) a constant pressure mode. Although turbines can be run directly on the expanding air during discharge, the preferred design mode is to inject a compressed air/oil mixture into a gas turbine. The design of "no-oil" second generation systems has started. One option is to store the heat of compression, and another option is to use a coal combustor to eliminate the need for oil in the power generation step.

Pneumatic Storage (Figure 20-6) describes residential and commercial scale application of compressed air storage using a constructed tank and air-driven turbine. Efficiencies are low unless there is recovery of the heat of compression in a total energy system.

Magnetic Energy Storage

Superconducting Magnet Energy Storage retains electrical energy in a magnetic field produced by a DC current circulating in the winding of a magnet. (See Table 20-2). The inductor makes use of the principle that the electrical current in a zero-resistance superconductor will flow indefinitely without loss. Because the energy is stored directly as electromagnetic energy, losses due to conversion of mechanical, thermal, or chemical energy to electrical energy are avoided. Energy losses occur from AC/DC conversion and from refrigeration power for the cooling of the superconductor.

DESCRIPTION OF THE FEDERAL STORAGE PROGRAM[2]

Federal Program Goals

- to develop and cooperate with industry in demonstrating reliable, cost-effective, and environmentally acceptable energy storage systems which will provide for:

Table 20-1. BATTERY STORAGE SUMMARY

	System Efficiency (%)	Useful Life (Years)	Operating Tempera-tures (°C)	Theoretical Cell Energy Density (Wh/kg)	Design/ Current Cell Energy Density (Wh/kg)	Design Volumetric Energy Density (kWh/m^3)	Depth of Discharge (%)	Current Density 10 hr rate** (mA/cm^2)	Capital Costs ($/kW)	Capital Costs ($kWh)	Demon-strated Cell Size (kWh)	Demon-strated Cell Life (cycles)	Critical Material
Lead Acid (Pb/PbO_2)	70-75	10	20-30	240	25	45	25	10-15	60-100	25-110	>20	>2000	lead
Sodium Sulfur (Na/S)	70-80	10-25	300-350	790	115/80-100	150	85	75	60-100	15-60	0.5	400	—
Sodium-Antimony trichloride ($Na/SbCl_3$)	70-80	10-25	200	770	110	120	80-90	25	70	15-25	0.02	175	antimony
Lithium-metal sulfide (LiS/FeS_2)	70-80	10-25	400-450	950	190/70-90	210	80	30	60-100	15-60	1.0	1000	lithium
Zinc-chlorine (Zn/Cl_2)	70-80	10-25	50	460	100	60	100	40-50 (5 hr rate)**	70	12-30	1.7	100	ruthenium (catalyst)
Zinc Bromine (Zn/Br_2)	70-80	10-25	30-60	430	60-70	90	90	30	—	—	0.01	2000	
Hydrogen Chlorine (H_2/Cl_2)	70-80	10-25	30-60	990	110	20	95	300	70	25-30	.001	50	platinum ruthenium (catalysts)
Iron-redox* (Fe/Fe^{+3})	—	20	20-50	155	45-75	60	100	40-60	100-200	5-10	10	>1000	—

*GEL, Inc., 1511 Peace Street, Durham, N.C. 27701. Timothy Gooley, Private Communication.

**Five and 10 hr rate refer to the rate at which the battery is discharged. At a 10 hr rate the cycled capacity of the battery (total capacity x depth of discharge) is increased by a low discharge rate.

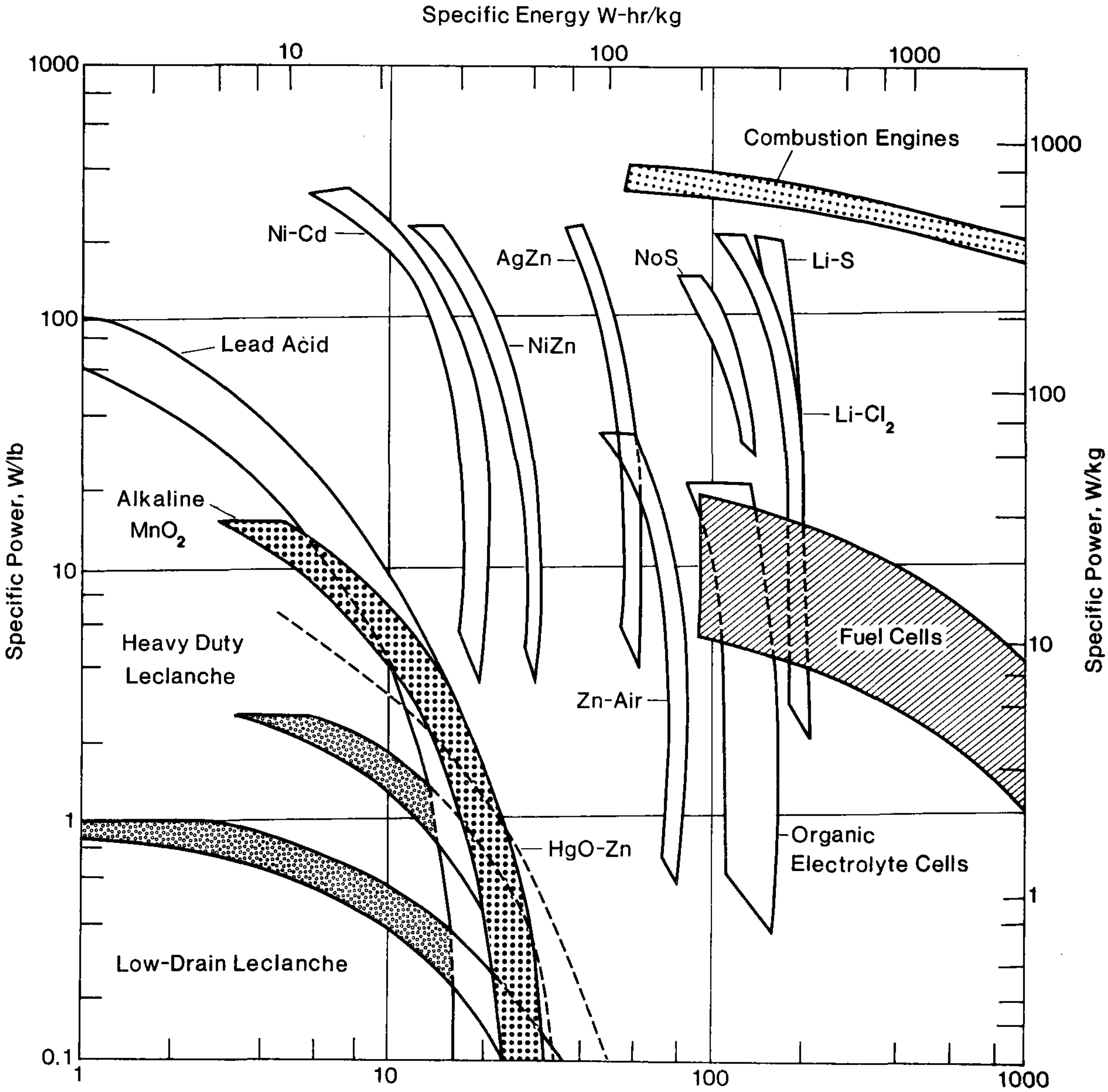
Sources: OTA Report, "Applications of Solar Technology to Today's Energy Needs," Vol. II, Chapter XIV.
EPRI (EM-264) and ERDA E(11-1)-2501 joint project report prepared by PSE and GCO, Newark, N.J., "An Assessment of Energy Storage Systems Suitable for Use by Utilities."

Table 20-2. MECHANICAL STORAGE SUMMARY

Energy Storage Concept	Key Characteristics: System Efficiency (%)	Useful Life (Years)	Nominal Range of Plant Size: Power Rating (MW)	Nominal Range of Plant Size: Energy Rating (MWh)	Capital Costs ($/kW)	Capital Costs ($/kWh)	Energy Density (kWh/m^3)	Special Hazard	Major Limitations Potential	Availability: *Development Status*	Availability: Development Requirements
Above-Ground Pumped Hydro	70-75	50	100-2K	1K-20K	90-180	2-12	1.4	None	Siting, environmental	Current State-of-the-Art	Incidental improvements only
Underground	70-75	50	200-2K	1K-20K	90-180	2-12	1.4	Flooding	Siting, environment	Basic Technology available	Higher head equipment
Underground Compressed Air	45-75	20-30	200-2K	2K-20K	100-210	4-30	0.7-35	Methane accumulation in cavern	Siting, cavern character	Initial implementation underway	Application design
Pneumatic Storage	55-65	20-30	up to 25kW	up to 100kWh	225	800	3.5-17	Rupture of high pressure tanks, high temp. discharge	Small scale	Proof of concept stage	System & component development
Inertial Storage Flywheel	70-85	20-30	<10kW to 10MW	<50kWh to 50MWh	65-120	50-300	17-70	Wheel disintegration	System complexity	Conceptual designs & experimental prototypes	Composite flywheel & system development
Super-Conducting Magnetic Storage	70-90	20-30	>10K	>1K	50-60	30-140	—	Possible magnetic field effects	Suitable siting	Conceptual components under development	Further concept development

Sources: OTA Report, "Applications of Solar Technology to Today's Energy Needs," Vol. II, Chapter XIV.
NSF Report #77SD4245 (1977) prepared by General Electric, "Applied Research on Energy Storage and Conversion for Photovoltaic and Wind Systems. EPRI (EM-264) & ERDA E(11-1)-2501 joint project report prepared by PSE & GCO, Newark, N.J., "An Assessment of Energy Storage Systems Suitable for Use by Utilities."

Figure 20-1. PERFORMANCE CAPABILITY OF VARIOUS BATTERY SYSTEMS



Source: N. Yao and J. R. Birk, "Battery Energy Storage for Utility Load Leveling and Electric Vehicles: A Review of Advanced Secondary Batteries." *IECEC Record, IIII* (1975). Copyright 1975. Institute of Electrical and Electronics Engineers. Reproduced with the permission of IEEE.

* the substitution of alternative energy sources for petroleum and natural gas;

* continuous service of solar and wind energy systems;

* the recovery of wasted energy from utilities and industries.

- to achieve the following objectives in the development of mobile and stationary systems:

  * batteries for transportation having an energy density of 140 Wh/kg, 1000 cycles, a power capability of 200 W/kg, and capital costs of less than $40/kWh;

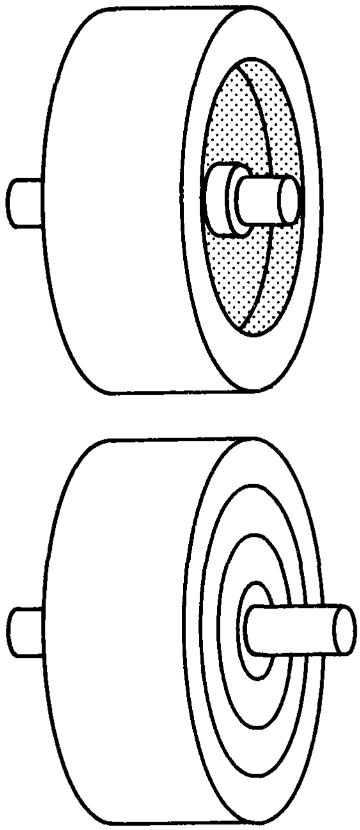
  * batteries for electric utility storage with a 10-year life and capital cost of $30/kWh;

  * batteries for photovoltaic applications with annual production by 1982 (1986) of 30 MWh (1000 MWh) at 0.4 h (2.0 h) discharge rate and storage costs of $50/kWh ($30/kWh); Post-1995 goal of $20/kWh;

  * flywheel regenerative braking systems for battery-powered vehicles with an energy density of 88 Wh/kg by FY85;

  * superconducting magnetic energy storage for large central storage of electricity with efficiency of 85 to

Figure 20-2. FLYWHEELS: STORING ENERGY AS MOTION

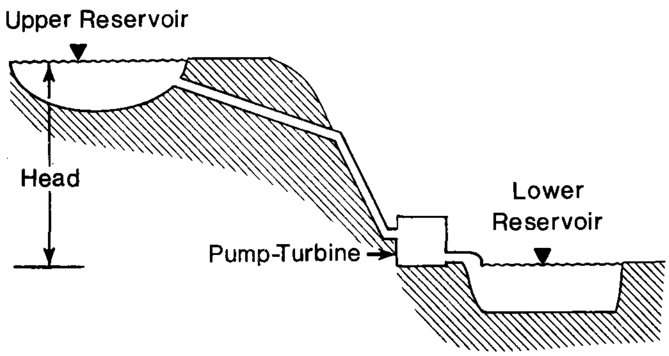


Source: DOE, Office of Public Affairs, November 1977.

90% and resulting power cost competitive with peaking and intermediate generators.

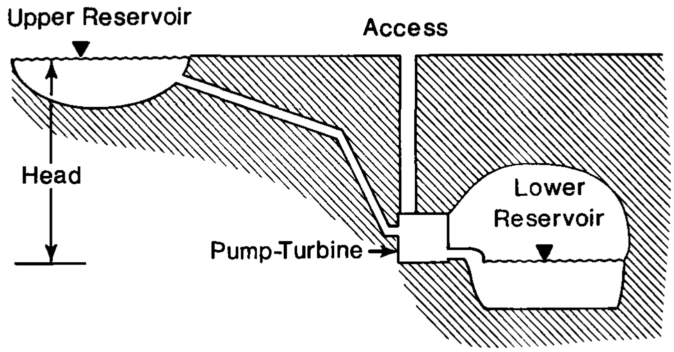
Responsibility for the DOE Storage R&D program resides in the Energy Storage Systems Division under the Assistant Secretary for Energy Technology. Where appropriate, projects are jointly funded with other divisions of Energy Technology (Solar Technology, Nuclear, Electric Energy Systems and Fossil), Conservation and Solar Applications (Solar Heating and Cooling Transportation, and Buildings and Community Systems), and with industry.

Figure 20-3. ABOVEGROUND PUMPED HYDRO STORAGE



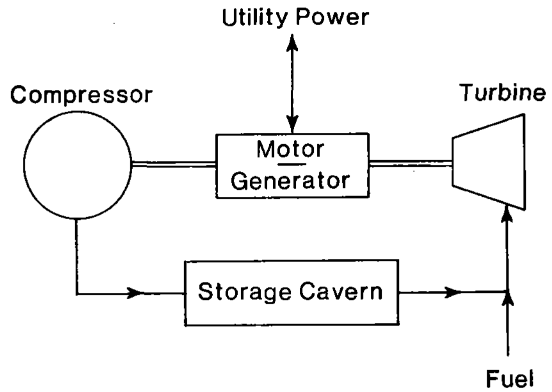
Source: General Electric Co. for NSF, Report No. 77SDS 4245, September 1977.

Figure 20-4. UNDERGROUND PUMPED HYDRO STORAGE



Source: G.E. (NSF) 77SDS 4245.

Figure 20-5. SCHEMATIC OF UNDERGROUND COMPRESSED AIR STORAGE



Source: G.E. (NSF) 77SDS 4245.

Funding for the Federal program is summarized in Figure 20-7 in thousands of dollars and is distributed by application as described in Table 20-3.

Table 20-3. APPLICATIONS AREAS SERVED BY ENERGY STORAGE BASE PROGRAM

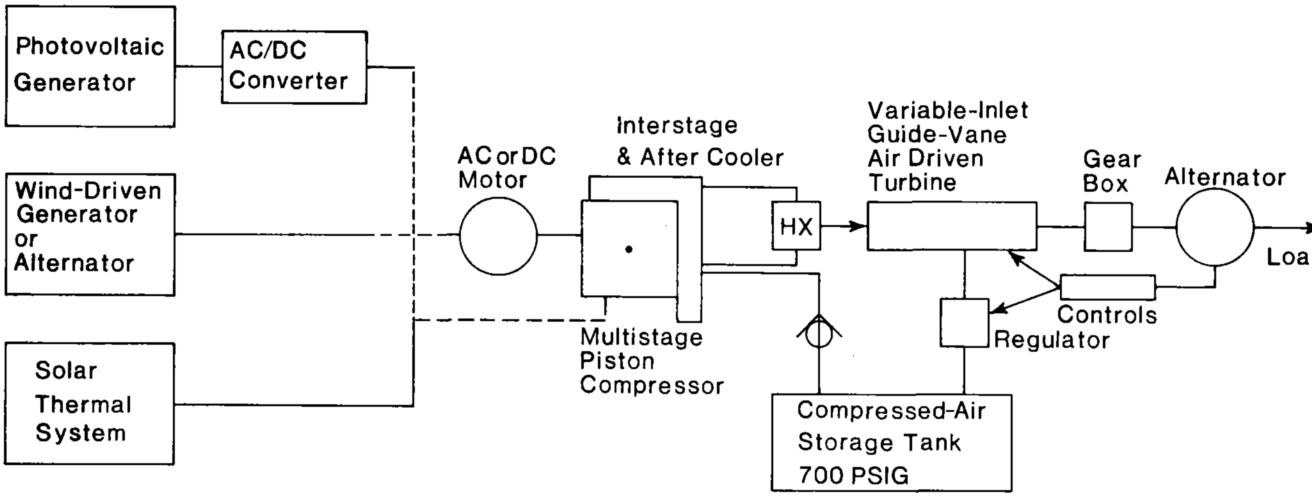
Percentage of FY 1978 Dollars in Each Area

Application	Batteries	Physical Systems	Analysis	Total
Transportation	56%*	15%	20%	36%
Solar	20	36	48	29
Utilities	20	29	30	25
Industry	4	20	2	10

*Includes batteries funding under EHV program.

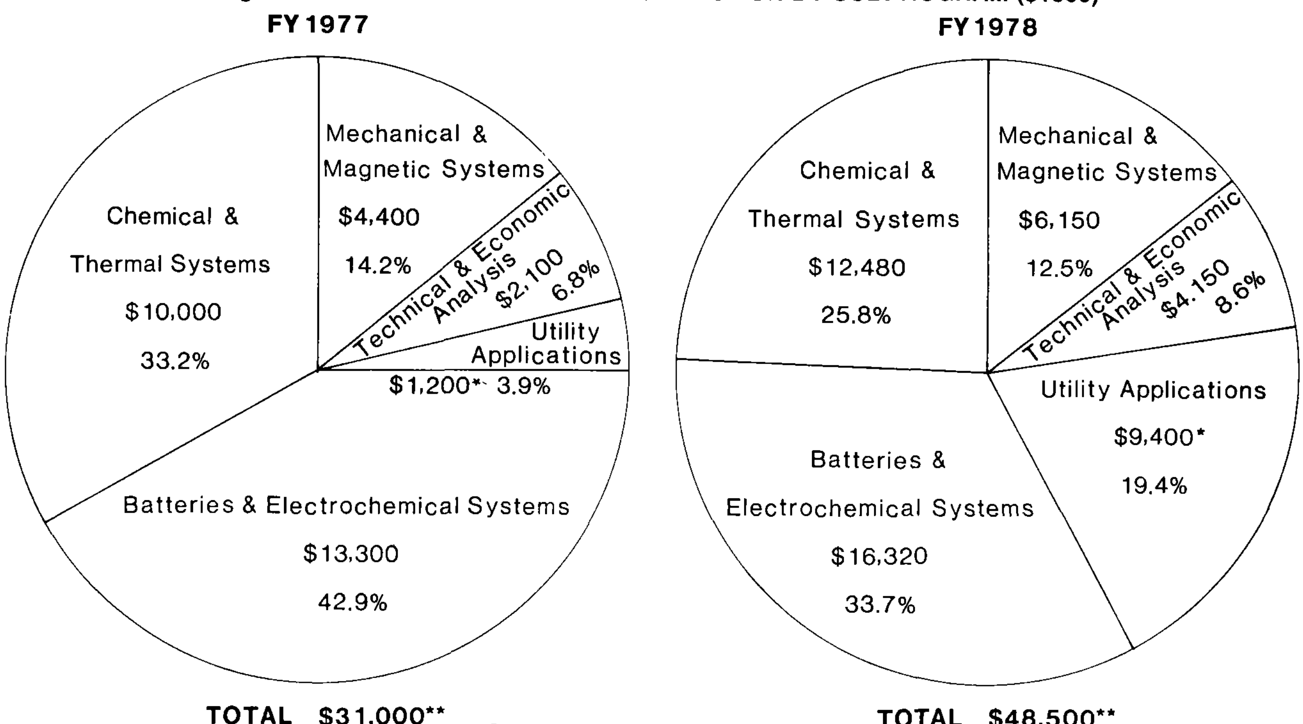
The Electric Power Research Institute (EPRI) has a program of battery development in six areas:[3] technology development, support activities, new concepts, power conditioning and control, technoeconomic studies, and testing. Within technology development, cost-sharing with private industry is supporting research on

Figure 20-6. SIMPLIFIED BLOCK DIAGRAM OF PNEUMATIC STORAGE SYSTEM



Source: G.E. (NSF) 77SDS 4245.

Figure 20-7. STORAGE FUNDING DISTRIBUTION BY SUBPROGRAM ($1000)



Source: DOE, FY78 Storage Program Plan.

*Jointly managed with EES. Funds in Energy Storage Systems Division Budget.
**Totals do not include funds from the Electric Vehicle Project Office which are being managed by the Division of Energy Storage Systems. Those funds total $7.0 million for FY77 and $5.7 million for FY78.

the following systems: sodium-sulfur, zinc-chlorine, sodium-antimony trichloride, lithium-metal sulfide and zinc-bromine. (See Table 20-1.) Twelve projects are funded with a total EPRI support of $4.6 million in FY77 and $5.6 million projected for FY78.

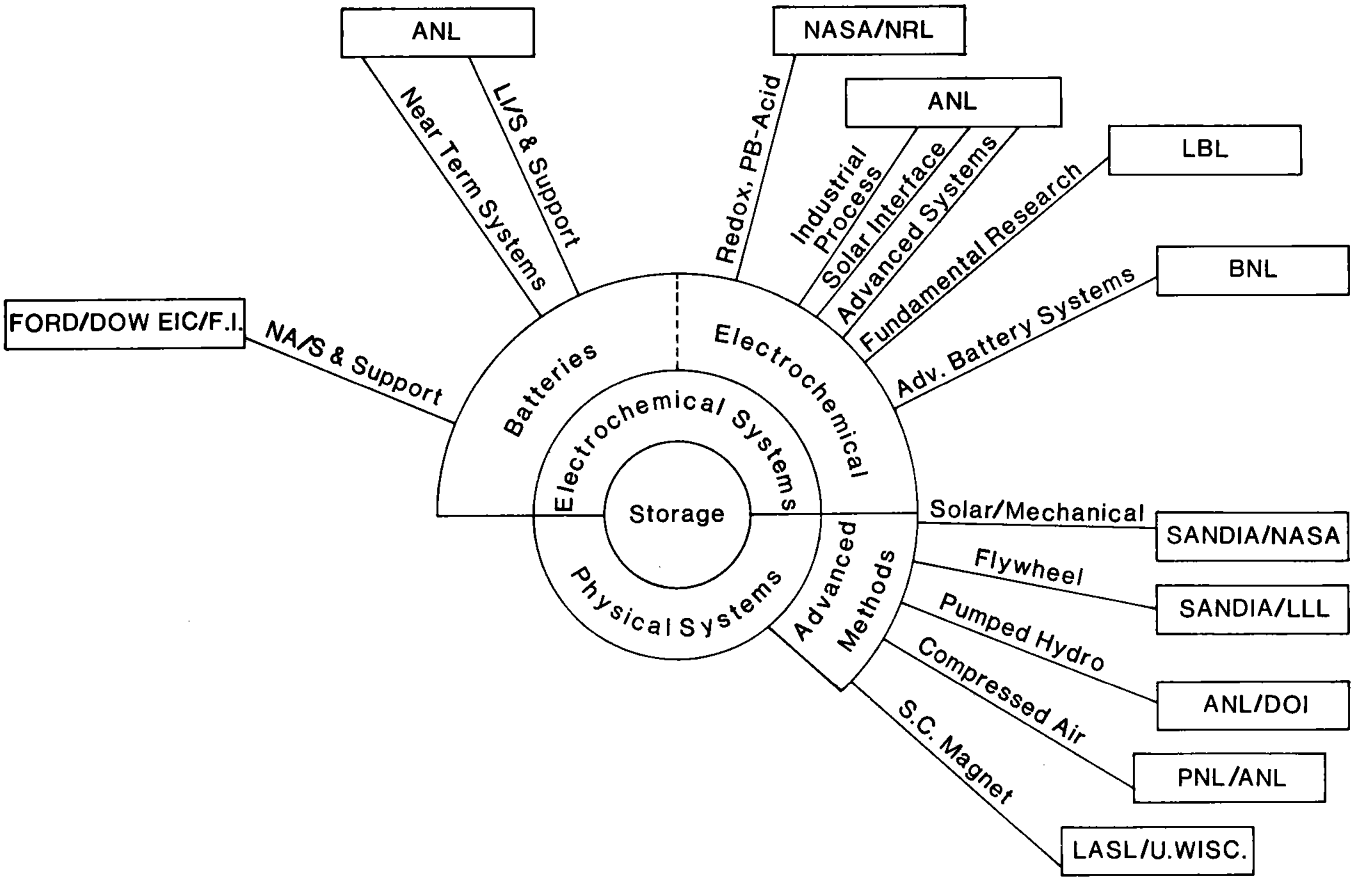
In addition, private industry R&D expenditures are estimated at $12-18 million in mechanical storage with approximately half in transportation applications, and $45-60 million in battery storage with more than half supporting rechargeable applications (DOE estimates).

Federal program responsibility is divided as indicated in Figure 20-8.

Two national battery test facilities are currently sponsored by DOE:

- The National Battery Test Laboratory at Argonne National Laboratory will be in operation during 1978 and is designed to test battery submodules up to 10 kWh with peak power of 125 kW. Up to five test bays will be available to evaluate the

Figure 20-8. STORAGE TECHNOLOGY BREAKDOWN BY LABORATORY



Source: DOE, FY78 Storage Program Plan.

performance of batteries for electric vehicles and submodules of batteries for utility load leveling.

- The Battery Energy Storage Test facility is designed to test utility scale battery modules. BEST is jointly funded by EPRI and the Electric Systems Division of DOE and is operated by PSE&G Co. of New Jersey. When completed in 1980, BEST will be instrumented to test three battery bays, each capable of 10 MWh storage and 5 MW peak power. BEST will emphasize performance evaluation; it is not designed for battery life testing.

Also, a DOD battery test facility, operated by the Navy, is located in Crane, Indiana.

Battery manufacturers and developers are members of, or are represented by, primarily five organizations: The American Electrochemical Society, Battery Council International (BCI), the Society of Automotive Engineers (SAE), the National Equipment Manufacturers Association (NEMA) and the battery subgroup of IEEE. An ad hoc National Advisory Committee has been formed during 1977.

DOE R&D Programs

Near-term battery research will continue on lead-acid, nickel-zinc and nickel-iron batteries for near-term demonstrations on electric vehicles. The private sector is sharing significant costs in this project. An advanced lead-acid battery for near-term load leveling is also under development and will support a proposed 100 MW peaking storage demonstration plant on an electric grid in the early 1980s.

The advanced lead-acid battery is also expected to be interfaced with solar electric demonstrations.

Advanced Battery Research Supports three advanced systems (LiS, Na-S, and $Zn\text{-}Cl_2$). The first tests of these batteries in vehicles are planned for 1979-1980. Tests for load-leveling applications are scheduled for 1980-1982 in the Battery Energy Storage Test (BEST) facility. Solar applications tests will be integrated with the development of solar energy systems.

Electrochemical Systems Research supports exploratory battery systems with 10% of the electrochemical budget. The following types of electrochemical couples are under investigation: redox, metal-air, hydrogen-halogen, and zinc-bromine.[4] At the end of FY78 a decision will be made on whether to continue funding present redox couples. A zinc-bromine battery workshop, sponsored by DOE and the Electric Power Research Institute (EPRI), will be held during FY78. Subsequently, a decision to select the best zinz-bromine approach for joint support by both organizations is planned.

The Solar Applications Program enhances the integration of battery storage with solar electric systems. Current studies concentrate on single residences, groups of residences, and commercial areas and utilities, and are being coordinated with the Division of Solar Technology. Studies of the battery requirements for a 500 MW photovoltaic generator will be started in FY78.[5]

The Support Research Program projects include bench scale studies of electrodes on charge and discharge, improved separators for molten salt cells, new solid electrolytes which conduct electricity by means of sodium or lithium ions,' and other fundamental research programs.

The Flywheel Program is designed to provide safe and economical flywheel systems for electric/hybrid vehicles. This program concentrates on developing composite rotors and advanced bearings, and improving flywheel dynamics. Laboratory and on-the-road testing of automotive flywheel systems will be performed from FY78 to FY81, with the objective of achieving initial large scale demonstration by FY82. Also in FY78, bearing performance and vacuum seal reliability will be emphasized.

The Mechanical Storage of Solar Energy Program is designed to develop pumped water, inertial, and pneumatic systems for storing solar/wind energy. Technical feasibility studies will be completed in FY78. Conceptual design of more promising systems (pneumatic, inertial) will be performed. Requirements for interfacing solar/electric systems with storage will be defined.

Compressed Air Energy Storage (CAES) is in the preliminary design phase of a 400 to 1000 MW demonstration system (jointly manged with Electric Energy Systems Division). Site criteria for CAES in salt caverns, aquifers, and depleted oil and gas fields are being developed in parallel. The development of a reversible compressor will also be emphasized in FY78.

Underground Pumped Hydroelectric Storage (UPHS) in FY77 initiated a project involving UPHS plant design, including site characterization in cooperation with the Division of Electric Energy Systems and EPRI. Emphasis of this program for FY78 is to determine the design characteristics of a high-head (approximately 3200 ft), flow-rate-controllable, reversible pump/turbine. This work will be supported by the capabilities of domestic and foreign pump/turbine manufacturers. A plan for development and testing of this type of machinery in subsequent years will be completed in FY78.

Superconducting Magnetic Energy Storage (SMES) is concentrating on the development of the technology for full scale systems in FY82 and a unit to demonstrate SMES technology by 1987. During FY78 the design of inexpensive magnet structural support units with very low heat leaks to the cryogenic magnet will be emphasized. Continued emphasis will be directed to the design and fabrication of an inexpensive superconductor. A cooperative effort with the Division of Electrical Energy Systems will be started on the design of a small scale (approximately 30 MJ) magnetic energy storage unit for installation by the Bonneville Power Administration. This device will be used for electrical transmission line stabilization.

PRINCIPAL DEVELOPMENTS IN FY77

- Zn-Cl^2 battery has progressed to 50 kWh size, sufficiently advanced to establish 30-month development program leading to a BEST facility test.
- BEST facility construction started. Shakedown of first battery bay with lead-acid batteries scheduled for 1979.
- Iron redox advanced battery concept (GEL Corp.) chosen for scaleup to 2 MWh size in photovoltaic/TES application at Mississippi County Community College, Arkansas.
- Completion of storage assessments[6] (Westinghouse, GE, Bechtel) and a workshop on Battery Storage for Solar Photovoltaic Energy Systems[7] have led to three general conclusions:
  * battery storage appears to be most promising of stationary storage systems for all applications (excluding pumped hydro where available);
  * storage connected to the grid appears more cost effective than does dedicated storage. For low solar penetrations in a system (<5%), storage and solar components can be treated independently;
  * until the late 1980s, lead-acid batteries appear to be leading candidates for stationary applications along with the possible rapid development of redox systems.
- Established safety of composites for flywheels. Reached 77 Wh/kg in a limited number of tests. Demonstrated flywheel/induction motor system in laboratory.
- Established technical feasibility of pneumatic solar storage. Long life and large number of cycles may offset projected cost of $100/kWh.
- Economic superconductor (titanium niobate in aluminum matrix) has been designed and tested in the laboratory.

ADVANTAGES OF ELECTROCHEMICAL AND MECHANICAL STORAGE

- Inertial systems can be charged and discharged quickly and have an extremely high number of charge/discharge cycles.
- Innovative designs using new composite materials are emerging.
- Pumped hydro systems have considerable operating experience. Low cost and plant lifetime has been documented.

- Underground compressed air offers the potential for further extraction of natural gas from underground rock strata.

- Lead-acid batteries have been used for 100 years in sizes up to 5 MWh. Sodium-sulfur batteries have an extremely high potential for high overall electrical efficiencies. Advanced batteries will have much higher energy densities than lead-acid batteries have.

- Batteries in general have short construction lead times, allow for distributed power "generation" and thus transmission credits, increase system stabilization with ability to absorb current and voltage fluctuations, have modular construction allowing for later expansion, and have potential for increasing the overall system reliability.

PROBLEMS, UNCERTAINTIES, DISSENTING VIEWS

- Inertial systems have no greater energy density than batteries and have destruction failure mode with associated shrapnel (however, composites disintegrate into "cotton candy" when failure occurs at low energy densities).

- For safety, large flywheels are sited with a vertical axis of rotation which leads to bearing load problems.

- Flywheel costs must come down by five times to be a viable alternative. Composites appear to be too expensive for stationary applications.

- Pumped hydro has land use constraints and is restricted to topographically suitable sites.

- Underground siting poses potential safety problems, and construction lead times are long—5 to 8 years.

- Underground compressed air will require that problems of water, air and noise pollution be considered.

- Methane accumulation may lead to safety hazards (although this effect could also be exploited as an advantage).

- Pneumatic systems have almost no operating experience, and design changes will be needed to overcome high costs.

- High pressure lines in a residential environment will require specific attention.

- Advanced molten sodium batteries must be sealed to prevent leaks.

- Lead-acid batteries have low energy densities (20 Wh/kg).

- Iron-iron redox battery for MC^3 application is facing scaleup problems from 100 Wh to 10 MWh.

Notes

[1]C. J. Todd, R. L. Eddy, R. C. James, W. E. Howell, "Cost Effective Electric Power Generation from the Wind," Aug. 1977. Div. of Atmospheric Water Resources Management, Bur. of Reclamation, Dept. of Interior, Denver, Colorado 80225.

[2]Management Review and Control Document, FY78, Energy Storage Systems; and personal communication, G. Pezdirtz, M. Katz, K. Klunder, G. Chang, and B. Webster, DOE Headquarters.

[3]EPRI Journal, Advance Systems Division Report, February 1976, p. 33 and EPRI Program Plan, 1977 and 1978.

[4]"*The Redox Flow System for Solar Photovoltaic Energy Storage*," NASA Technical Memorandum X-73562, P. O'Donnell, R. F. Gahn, and W. Pfeiffer.

[5]A. Beaufrere, R. S. Yeo, S. Srinivasan, J. McElroy, and F. Hart, "A Hydrogen-Halogen Energy Storage System for Electric Utility Applications," in *Proceedings*: 12th IECEC, Washington, D.C., August 29-September 2, 1977.

[6]Ibid. Also see *Applied Research on Energy Storage and Conversion for Photovoltaic and Wind Systems*, NSF Report #77SDS4245 prepared by General Electric (1977); and *Battery Storage Performance Requirements for Terrestrial Solar Photovoltaic Power Systems*, report by Bechtel Corporation under Argonne National Laboratory Subcontract 31-109382962 (1978).

[7]Workshop organized by Argonne National Laboratory and held at the Denver Hilton, January 11-13, 1978.

21. SOLAR MATERIALS ACTIVITIES

BASIC TECHNICAL DESCRIPTION

Solar materials research and development has been viewed as a supporting technology by DOE. Responsibility for materials R&D at DOE is divided among Energy Technology (ET), Conservation and Solar Applications (CS), and Energy Research (ER). Projects range from basic materials understanding to material specification for various solar test fields.

FEDERAL PROGRAM GOALS

The goals of the Federally funded programs in basic research were to:

- advance the understanding of basic structures and mechanisms governing materials properties, including those of interest for solar energy conversion;
- provide a foundation for materials technology through the development of basic knowledge in energy-related materials, including solar energy problem areas;
- exploit the unique capabilities and facilities of the national laboratories for conducting materials sciences research.

The goals in the Federally funded, project-oriented activities were to:

- provide materials options for solar systems designers;
- provide necessary materials property data;
- generate evaluation and acceptance criteria for materials.

DESCRIPTION OF THE FEDERAL MATERIALS PROGRAM IN FY77

The basic research tasks as funded by Energy Research are shown in Table 21-1.

Table 21-1. BASIC MATERIALS RESEARCH TASKS FUNDED BY THE DIVISION OF BASIC ENERGY SCIENCES

	FY77 Funding $K
advanced research on photovoltaic silicon	190
new photovoltaic materials, non-silicon	450
ion implementation techniques for doping photovoltaic materials	300
theoretical solid state physics of photovoltaic and photovoltaic thermal materials	100
photophysical processes in solar energy conversion	450
optical properties and selective absorber materials for solar energy photothermal conversion	320
electrode materials for photo-assisted hydrogen production and other chemical reactions	250
working fluids	100

Source: ERDA 77-123.

The remainder of the Federally supported materials research and development was tied directly to DOE (ET and CS) projects, so the actual spending in those areas can only be estimated (brackets) in Table 21-2.

Table 21-2. ESTIMATED BUDGET FOR PROJECT-RELATED MATERIALS ACTIVITIES

	FY77 Funding $K
reflector materials	[300]
polymeric lens materials	[250]
mirror support materials	[350]
absorber surface materials	[699]
materials optical testing	[675]
basic materials research and development	[100]
flywheel materials	[150]
storage materials	[200]
glazing materials	[100]
life testing	[200]

Source: Mark Adams, "Materials Summary & Technology Plan Outline," Technology Summary Plan Workshop, June 22-23, 1977, Sponsored by ERDA/JPL.

The research and development funds were directed mostly through national labs, which, in turn, involved universities and large and small contractors.

PRINCIPAL DEVELOPMENTS IN FY77

- In the basic research and development areas, the solar-limiting materials properties were better defined.
- In the applied research areas, materials and systems were studied to define where materials advances would benefit solar technologies.
- Materials were specified, tested, and accepted for major DOE facilities.
- Laser-ray-trace and bidirectional reflectometry research tools were developed to characterize mirrors and optical reflectors.
- Processing specifications and quality of Black Chrome selective absorbers were improved.
- Thin glass reflectors were identified as advanced reflector candidates.
- Advanced cast-acrylic fresnel lenses were developed.
- Heliostats were refined.
- The effects of material stability during weathering were better defined.

The basic materials research activities have progressed slowly, as would be expected for long-range research. The above list is not all-inclusive but does reflect the types of materials results which have been obtained.

ADVANTAGES OF MATERIALS RESEARCH

Materials research aimed at modifying or inventing materials for solar energy conversion systems will result in higher quality and lower life-cycle-cost systems. Materials development plays an important supporting role to both highly technical and nonsophisticated solar systems. Systems advances in FY77 have stimulated the materials science community to develop the data required by emerging solar conversion technology.

PROBLEMS, UNCERTAINTIES DISSENTING VIEWS

Because of the wide variety of solar programs and projects, many research activities have been duplicative. The funding divisions of DOE have not made a major effort to coordinate their spending in materials research. Solar selective-absorber research is funded by three separate groups at DOE—Solar Thermal Power, Heating and Cooling, and Basic Sciences. Close coordination through a central focus like SERI should improve productivity in generic materials research by reducing duplication. The DOE program has been mainly project-oriented, fostering applied research. Long-range materials research, with both high risks and potential payoffs, has not been strongly supported.

22. ENERGY RESOURCE ASSESSMENT

BASIC TECHNICAL DESCRIPTION

The assessment of deliverable energy from various solar energy conversion systems requires an accurate physical description of the potential solar energy resource. Energy resource assessment provides the detailed physical descriptions and geophysical data for the various solar energy resources. The various potential solar energy resources are insolation (sunlight), wind, biomass, falling water, ocean temperature/salinity differences, waves, and currents. In general, a significant amount of information exists for these potential energy resources; however, these past data were not collected specifically for inputs to the design and evaluation of solar energy conversion systems. Much effort now is required to convert past data to forms useful to the solar energy resource evaluations and assessments. Similar problems and effort exist regarding physical models for the various solar energy resources. In many cases, new data will have to be collected and new physical models developed in order to assess the amount of energy solar resources actually can deliver.

FEDERAL PROGRAM GOALS

The general goal of the Federal energy resouces assessment program is to collect, standardize, certify, process, and produce geophysical data for solar energy applications. The achievement of this goal will assure proper designs of the various solar energy conversion systems and accurate estimates of the actual energy deliverable from solar energy resources. The accurate estimate of the deliverable, as opposed to just the potential, energy from solar sources is critical to the planning and execution of the overall national energy program.

DESCRIPTION OF FEDERAL PROGRAM

The Federal program for solar energy resource assessment is concentrated in three major areas—solar radiation, wind, and ocean energy. The major tasks in each area are to (1) convert existing data to some useful, standardized, certified form, and (2) to collect new data and/or develop physical models as required.

The activities in the solar radiation area comprise a multiagency and multiinstitution effort directed at providing data and physical models for the solar radiation parameters of direct, diffuse, and global radiation. The direct radiation is that energy coming directly from the solar disc. The diffuse radiation is the skylight, which is created by atmospheric scattering of the direct radiation. The total radiation at the surface of the earth is known as the global radiation and is simply the sum of the direct and diffuse radiation. The major Federal efforts have been to (1) rehabilitate, certify, and standardize extensive past global radiation data collected by the National Weather Service, and (2) initiate an improved data collection network which includes both the direct and global measurements/data. The improved network consists of 38 stations and will be operational during 1978. The new data will be available from the National Climatic Center. (This data base is now known as SOLMET and SOLDAY, archived at the National Climatic Center 704/258-2850, extension 203.) Other activities concerned with the solar radiation energy source include: (1) study performance and model development to allow extrapolation of the individual network site data to other locations; (2) development of models which can infer solar radiation parameters from the commonly available measurements and observations at National Weather Service stations; (3) specific measurement programs to define the character of solar radiation in variable climatic conditions such as rural-urban, mountain-valley, and coastal-inland; (4) initiation, during 1978, of a university based programs to provide training and more complex, higher quality measurements and analyses of solar radiation and meteorological parameters; (5) generation of standard meteorological years for each of 26 stations (SOLMET) in the United States; and (6) studies directed toward determining the feasibility of and methods for forecasting solar radiation.

The activities in the wind and ocean energy areas consist of identifying data sources, compiling the data into useful format, and performing the required data analysis. Selected data will then be incorporated into the resource data base, archived at the National Climatic Center. A wind data inventory has been completed by the National Oceanic and Atmospheric Administration.

APPENDIX 1

MAJOR ENERGY EVENTS OF 1977[1]

January

A record cold winter causes "the worst energy crisis in the nation's history."[2] Much of the country experiences a severe natural gas shortage, and for one day (it is later revealed) the entire electrical system of the eastern U.S. is in danger of collapse.

The first two-tiered price system in OPEC's history goes into effect on January 1, with Saudi Arabia and the United Arab Emirates raising prices only 5% instead of the general 10%.

February

Over 1.2 million workers are laid off as factories close due to lack of natural gas, in the worst week of the winter crisis.

The Emergency Natural Gas Act is passed by Congress February 2. It gives the President power, through the FPC, to approve emergency gas deliveries and to exempt emergency sales from price regulations (to expire in April).

March

The world's first commercial high temperature gas-cooled reactor begins producing electricity 45 miles north of Denver, Colorado.

The *Solar Energy Research Institute* contract is awarded to Midwest Research Institute and is to operate in Golden, Colorado.

April

The U.S. will not reprocess spent fuel or recycle plutonium, according to a Presidential announcement.

President Carter announces his National Energy Plan to the nation on April 18 with details to Congress on April 20. He terms the effort "the moral equivalent of war."

West Germany's intention to increase exports of plutonium-based reactors is underscored by its approval, on April 27, of a $2.7 billion research program aimed at such exporting.

The 1968 disappearance of a 200-ton load of uranium ore on a sea route from Belgium to Italy is reported on April 28 and later confirmed. It is believed that the uranium was diverted to Israel for nuclear weapons production.

A group of 1415 demonstrators is arrested while occupying the partially constructed nuclear reactor in Seabrook, New Hampshire.

An offshore Norwegian oil well blowout is finally plugged on April 30, after being out of control several days.

The National Center for Appropriate Technology is established in Butte, Montana.

May

The first regional solar center grant is awarded to Northern Energy Corporation of Cambridge for the Northeast Center.

Sandia Laboratory's solar thermal test facility becomes operational at 1.7 MW, to increase to 5 MW by the end of the year.

June

The Alaska pipeline begins transporting oil on June 20.

July

The Strategic Petroleum Reserve is begun with the delivery of the first shipment of oil to storage in Louisiana.

OPEC members Saudi Arabia and the United Arab Emirates increase oil prices an additional 5% while other OPEC nations retain their prices, thus ending the two-tier price system.

Plutonium-producing breeder reactors win additional endorsement from Belgium, France, Italy, the Netherlands, and West Germany as the five nations sign agreements to support further research and development in the technology.

An Alaskan oil pipeline explosion kills one worker and injures five on July 8.

A 25-hour blackout in New York City on July 13-14 is accompanied by uncontrolled looting and arson in parts of the city, resulting in many millions of dollars in losses.

Alaskan oil reaches the port of Valdez on July 28, more than 38½ days after it left Prudhoe Bay. The journey should have taken 7½ days.

A protest against the Phoenix, France's fast breeder reactor, becomes violent and results in the death of a demonstrator.

August

The House of Representatives passes the National Energy Act in much the form requested by President Carter.

The Surface Mining Control and Reclamation Act, PL 95-87, requiring mine operators to restore stripped land, is signed into law.

The Clean Air Act Amendments are signed into law. The law tightens emissions standards for new stationary sources.

Oil from the Alaska pipeline is delivered in California on August 9.

September

The U.S. and Canada agree on the 2700-mile Alcan route for a natural gas pipeline.

Alaskan oil reaches its first eastern U.S. port as it arrives by tanker in Delaware on September 17.

October

The newly created Department of Energy begins operations with a staff of 19,000 (eighth largest in the Cabinet) and a budget of $10.5 billion (tenth largest).

A proposal to establish an international atomic fuel bank and to assume responsibility for the storage and disposal of spent nuclear fuel here and abroad is made by President Carter.

The Senate passes five energy-related bills differing substantially from Carter's requests. Two conference committees are set up to reconcile House-Senate differences.

November

The Supreme Court agrees to rule on the constitutionality of the Price-Anderson Act, which limits the liability insurance requirements of private nuclear reactors.

Construction of a U.S.-Mexico gas pipeline, 821 miles long, is scheduled to begin.

The EPA issues drilling permits to 10 major oil companies for the Baltimore Canyon, off the coasts of New York and New Jersey.

December

The United Mine Workers strike the nation's coal mines beginning on December 6.

OPEC agrees not to raise oil prices for the present.

Congress adjourns without having passed an energy bill.

TRENDS 1977

U.S. dependence on foreign oil increases; imports total about 46% of demand, averaging 8.5 million barrels/day. In 1976 imports averaged 7.3 billion barrels/day, or 42% of demand.

Cost of foreign oil rises to $45 billion, $11 billion more than in 1976. The U.S. trade deficit amounts to $30 billion.

Total U.S. oil demand rises between 5% and 8%.

Oil gluts last throughout the year. The condition is worldwide, but especially acute on the West Coast.

Prices of fuels rise. Through mid-year, utilities pay 12.3% more for coal, 16.3% more for oil, and 24.3% more for gas than in 1976. Figures are similar for households and businesses.

One new nuclear reactor order is placed in 1977.

Fusion power receives a boost with a five-fold improvement in plasma containment in the Alcator Tokamak at MIT.

Gas companies make preliminary arrangement for LNG from Algeria and Indonesia. However, Secretary Schlesinger's announced inclination against allowing the companies to average in LNG prices threatens the future of LNG.

The Consumer Price Index rises 6.5%.

Notes

[1]The sources for the information in this section are: "Chronology of Events," *1978 Brittanica Book of the Year* (Chicago:: Encyclopedia Brittanica, Inc., 1978), pp. 30-53; Edward K. DeLong, "U.S. Energy Crisis: Saving Fuel Viewed as Correct Solution," *Rocky Mountain News,* "Trend" section, December 25, 1977, p. 7; Bruce C. Netschert, "Energy," *1978 Brittanica Book of the Year,* pp. 353-60; and Joe Reilly, "Energy 77: A Review," prepublication draft (New York: Environment Information Center, Inc., 1978).

[2]Netschert, p. 353.

APPENDIX 2

GLOSSARY

Absorptance The dimensionless ratio of solar energy absorbed by a surface to the incident solar energy striking it; the frequency spectrum of the ratio must be specified.

Absorption The process by which radiation is captured within a material. Also used to describe a cooling technology in which one material is first evaporated with heat input and later reabsorbed with heat release displacing the need for a compressor.

Absorption Air Conditioning A cooling technology in which one material is first evaporated or desorbed (with heat input) and later reabsorbed (with heat release) replacing a compressor.

ACES See Annual Cycle Energy System.

Active solar system An assembly of collectors, thermal storage device(s), and transfer fluid which converts solar energy into thermal energy, and in which energy in addition to solar is used to accomplish the transfer of thermal energy.

Active system A solar heating or cooling system that requires external power to operate the system.

Adsorption The adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surface of solid bodies or liquids with which they are in contact. Used also to describe a form of solar cooling employing this principle.

AEC See Atomic Energy Commission.

Agency for International Development A branch of the U.S. government.

Agricultural and industrial process heat Both an end-use application for thermal energy and the name applied to that portion of the national solar program developing solar technologies for this end-use sector.

AID See Agency for International Development.

AIPH See agricultural and industrial process heat.

Air mass The length of the path through the Earth's atmosphere traversed by the direct solar radiation, expressed as a multiple of the path length with the sun at zenith.

Albedo The reflecting power expressed as the ratio of light reflected from an object to the total amount falling on it.

Amorphous silicon A noncrystalline semiconductor material having only short range order in its structure. Amorphous semiconductors hold promise for low cost photovoltaics.

Anaerobic digestion The process by which organic matter is decomposed by bacteria which work in the absence of free oxygen, with the release of a burnable mixture of gases.

Annual Cycle Energy System A system in which heat is withdrawn from a large volume of water in the winter; the block of ice so produced is used for summer cooling.

Aquifer A water-bearing stratum of permeable rock, sand, or gravel used for storage of low-temperature thermal energy.

Array As in thermal or electrical solar array. A number of individual solar collection devices arranged in a suitable pattern to collect solar energy effectively.

ASHRAE Acronym denoting the American Society of Heating, Refrigeration and Air Conditioning Engineers, 345 E. 47th Street, New York, New York 10017. ASHRAE Handbooks are sources of basic data on heating and air conditioning.

Atomic Energy Commission A predecessor agency (pre-1975) of the Energy Research and Development Administration which itself was replaced by the Department of Energy in 1977.

AWEA American Wind Energy Association.

Azimuth The angle between the south-north line at a given location and the projection of the earth-sun line in the horizontal plane.

Baseload plant (Baseload electricity) An electrical generation facility designed to satisfy a continuous demand.

Battery Energy Storage Test (facility) An experimental laboratory in Hillsborough Township, New Jersey, for the testing of electric storage batteries; jointly funded by the Electric Power Research Institute and the Department of Energy.

bbl — Barrels (of oil). One barrel equals 42 American gallons, 306 pounds, 5.6 cubic feet. The heat content is approximately 5.8 x 10^6 Btu/bbl.

BCI — Battery Council International.

BEST — See Battery Energy Storage Test facility.

Biconversion — The conversion of organic matter to more useful forms of stored energy using biological processes. An example of bioconversion is the digestion of solid wastes by microorganisms to form methane.

Biofouling — The formation of film and/or slime on a substrate from attachment of micro- and macro-aquatic organisms; can occur under freshwater and saltwater conditions, which is a concern of the Ocean Thermal Energy Conversion Program.

Biomass — Any material derived from growing organisms such as agricultural products and residues, trees, wood and bark residues, animal manures, and algae. This word has come into common use for discussions of productivity of photosynthesis and energy use of cellulose materials irrespective of species.

Biophotolysis — The action of light on a biological system which results in the dissociation of a substrate, usually water, to produce hydrogen.

Black body — Term describing an ideal substance which would absorb all the radiation falling on it and reflect nothing. An alternative definition is a body which emits the maximum possible radiation; i.e., its emissivity is 1.0.

Brayton cycle — A thermodynamic cycle consisting of two constant-pressure processes interspersed with two constant-entropy processes. Known also as complete-expansion diesel cycle or Joule cycle. Jet turbine engines are an example.

BSF cell — Back surface field solar cell. See high-low emitter cell.

Btu — British thermal unit. The amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Capacity factor — The actual amount of electricity generated by a power plant during a time interval divided by the amount of electricity that would be generated by the plant during the same interval if it operated at maximum capacity.

Capital-intensive — Indicates that a relatively large percentage of the total costs of production, as for solar technologies, are associated with the initial costs rather than the operating costs. Also used in another sense to differentiate from technologies which are labor-intensive.

Carbon dioxide — A relatively minor constituent of air used by plants to produce biomass. Also released in the combustion of fossil fuels in such quantities as to cause concern over possible future earth climatic changes.

CBO — Congressional Budget Office.

CEQ — See Council on Environmental Quality.

Closed-cycle ocean thermal energy conversion — A form of ocean thermal energy conversion (OTEC) using a working fluid such as ammonia or propane which can be vaporized by warm ocean surface waters and condensed with cool, deep ocean waters, and then returned to be vaporized again in a closed loop.

CNRS — Centre Nationale de la Recherche Scientifique; organization running the solar furnace in France.

CO_2 — See carbon dioxide.

Coefficient of heat transmission — The rate of heat loss in Btu per hour through a square foot of a wall or other building surface when the difference between indoor and outdoor air temperatures is 1°F. Often called a U-value.

Coefficient-of-performance — The ratio of the useful energy output from a device to the incoming energy. For heat pumps the COP can be as large as 4 or 5; one unit of electricity can transfer 3 or 4 units of outside energy indoors while still converting the unit of electricity to usable thermal energy.

Collector — See solar collector.

Collector efficiency — The ratio of the energy collected by a solar collector to the radiant energy incident on the collector.

Collector tilt angle — Angle at which a collector is slanted up from the horizontal plane.

Committee on Nuclear and Alternative Energy Sources — Special committee established by the National Research Council of the National Academy of Science. Was in existence from 1975 to 1977.

Community Services Administration — The successor federal agency to the Office of Economic Opportunity which has had major responsibility in reducing energy costs for low-income families. CSA is funding the National Center for Appropriate Technology in Butte, Montana, which is involved in low-cost solar technology development and deployment.

Compound parabolic collector A form of concentrating collector which need not track the sun.

CONAES See Committee on Nuclear and Alternative Energy Sources.

Concentrating collector A device which uses reflective surfaces to concentrate the sun's rays onto a smaller area, where they are absorbed and converted to heat energy. Concentration ratios over 10,000 have been achieved.

Concentration ratio The ratio of the received energy on a small area from a curved mirror or multiple flat surfaces with perfect reflectivity to that arriving from the sun. Often measured in "suns." Commonly used to refer to the ratio of aperture to receiver areas.

Concentrator cell assembly The smallest complete assembly of solar cells—which may be environmentally protected—designed to generate DC power under concentrated terrestrial sunlight.

Conductance A property of a slab of material equal to the quantity of heat in Btu per hour that flows through one square foot of the slab when a 1°F temperature difference is maintained between the two sides.

Conduction Transmission of energy through a medium which does not involve movement of the medium itself.

Convection Transmission of energy or mass through a medium involving movement of the medium itself. Or heat transfer owing to fluid.

Conversion efficiency The actual net output provided by a conversion device divided by the gross input required to produce the output.

Conversion system A device or process that converts a raw energy form into another, more useful form of energy. Examples: conversion of wood into methanol or sunlight into electricity.

Cooling degree day One day with the average ambient temperature warmer than 75°F.

COP See coefficient-of-performance.

Council on Environmental Quality A utility regulatory organization whose duties were assumed by the Federal Energy Regulatory Commisssion in October 1977.

Counter-flow heat exchanger Device in which two fluids flow in opposite directions with one fluid transferring heat to the other.

CPC See compound parabolic collector.

CRS/LOC Congressional Research Service/Library of Congress.

Cryogenics The physics of low-temperature materials; used in superconducting magnetic storage.

CS Office of the Assistant Secretary for Conservation and Solar Application within the Department of Energy. Also abbreviated CSA.

CSA See Community Services Administration. Also see CS.

CSU Colorado State University.

Darrieus machine A vertical axis wind machine that has long, thin blades in the shape of loops connected at the top and bottom of the axle; often called "eggbeater" windmill because of its appearance.

Data base A set of numbers, variables, and information that is used to provide the operational criteria for processing and decisionmaking.

Decentralized systems In solar systems, refers to establishment of autonomous units such as households or neighborhoods to provide electricity or heat.

Degree day See heating degree day and cooling degree day.

Demand The amount of energy required to satisfy the energy needs of a stated sector of the economy. See also end-use-demand.

Department of Agriculture Responsible for several years for such portions of the solar program as small wind machines and some biomass activities. Congress mandated a major solar demonstration program in 1977.

Department of Defense Mandated in 1974 by Congress for demonstration of solar heating and cooling devices; also active in photovoltaics utilization.

Department of Energy Created by law; started operation in October 1977. Responsible for all U.S. federal energy activities. It combined all solar activities previously existing in the Energy Research and

Development Administration and the Federal Energy Administration, both of which it replaced.

Department of Housing and Urban Development The federal organization responsible for most of the residential solar heating and cooling demonstration program.

Desorption The process of removing a sorbed substance by the reverse of adsorption or absorption.

Diffuse insolation The scattered solar power density falling on a surface of given orientation from the sky, and, in the case of an inclined surface, reflected from the ground as well (watts/m^2). This does not include direct insolation. See total insolation.

Digester A device using anaerobic bacteria to decompose organic wastes to produce methane.

Direct insolation The solar power density from the sun falling on a surface of given orientation (watts/m^2). Often, the direct insolation is measured with equipment whose acceptance angle is as large as 6 degrees, rather than the ½ degree of the solar disc.

Distributed system See decentralized systems.

Diurnal Active or occurring during the daytime rather than at night; daily.

DOA See Department of Agriculture.

DOD See Department of Defense.

DOE See Department of Energy.

Doping Controlled addition of impurities to a semiconductor to alter its electrical properties, a necessary step in making solar cells.

Economic Regulatory Administration A successor to the Federal Energy Administration; has a mandate which includes intervention in rate and siting cases which can affect solar deployment. Part of DOE.

Edge-defined film-fed growth Method of growing thin "ribbons" of single crystal material by pulling from melt through a die.

EFG See edge-defined film-fed growth.

Electric Power Research Institute Located in Palo Alto, California; the principal research arm of U.S. electric utilities with a sizable solar program.

Electrolysis The use of an electric current to produce hydrogen and oxygen from water.

Electrolyte A substance that conducts electricity by the transfer of ions.

Emissivity See emittance. Emissivity refers to the same parameters for an optically smooth substance with an uncontaminated surface.

Emittance The ratio of the radiant energy emitted from a surface at a given temperature to the radiant energy that would be emitted by a perfect black body at that same temperature. It should specify surface conditions and then refer to measured quantities. (See emissivity.) May be used to refer to angular [watts/(m^2 · steradian)] or spectral [watts/(m^2 · micrometer)] properties as well as total hemispherical radiation.

End-use-demand The amount of energy used by final consumers, often given by type of end-use. Sometimes measured in primary energy equivalents, which can include conversion losses. Electrical end-use-demands provided by solar sources are sometimes converted by 1/0.65 to 1/0.75 to reflect typical boiler or furnace efficiencies. Care must be exercised in interpreting end-use-demand data. See energy supply and primary energy.

Endothermic reaction Chemical reaction with absorption of heat.

Energy efficiency ratio The amount of useful work or product divided by the fuel or energy input. Example, in electrical generation it is the amount of electricity produced per unit of fuel consumed; for an air conditioner, it is the amount of cooling provided per unit of electricity used.

Energy farm A concept involving the farming of selected plants for the purpose of providing biomass that can be used as a fuel or converted into other fuels or energy products.

Energy plantations The growing of plant material for its fuel value; a renewable source of energy-rich, fixed carbon produced by photosynthesis.

Energy Research and Development Administration Predecessor (before October 1977) to the Department of Energy. Succeeded the Atomic Energy Commission in January 1975.

Energy supply The total amount of primary energy resources used. For solar sources, energy supply data are often expressed in fossil equivalents. See end-use-demand.

EPRI See Electric Power Research Institute.

ER See Office of Energy Research (DOE).

ERA See Economic Regulatory Administration.

ERDA See Energy Research and Development Administration.

Escalation rate A number which defines the annual increase in monetary value of a specified quantity.

ET See Office of the Assistant Secretary for Energy Technology.

Ethanol Ethyl alcohol or grain alcohol, C_2H_5OH. It is the alcohol contained in intoxicating beverages. Ethanol can be produced from biomass by the conversion process called fermentation.

Eutectic salts A mixture of two salts with a melting point lower than that of any other combination of the same components. Attractive in solar applications at both low and high temperatures because of the large amount of heat which can be stored and recovered in the phase change in a relatively small volume.

EVA-ADAM A proposed method of transporting energy wherein methane and water are catalytically reacted with a high-temperature source of energy to carbon monoxide and hydrogen. These products are then transmitted to a site where they catalytically react to form methane and water, releasing energy. The methane and water are then returned in a second pipe (a chemical heat pipe) to the source of energy to repeat the cycle.

Evacuated tube collector A collector manufactured from concentric glass tubes with an evacuated space between the tubes. They are very efficient at relatively high (about 100°C) temperature differences.

Exothermic reaction Chemical reaction with evolution of heat.

FCHART A computerized method for predicting the performance of solar space and hot water heating systems.

FEA See Federal Energy Administration.

Federal Energy Administration Absorbed into the Department of Energy in October 1977. Previously responsible for solar commercialization.

Federal Energy Office The predecessor of the Federal Energy Administration.

Federal Power Commission A utility regulatory organization whose duties were assumed by the Federal Energy Regulatory Commission in October 1977.

Feedstock A raw material that can be converted to one or more end-products (methanol or synthetic natural gas, for example). Biomass is an energy feedstock.

FEO See Federal Energy Office.

Fermentation Decomposition of organic material to alcohol, methane, etc., by organisms, especially bacteria and yeasts, usually in the absence of oxygen.

FFB See Fuels From Biomass.

Flat-plate collector A solar collection device in which sunlight is converted to heat on a plane surface, without the aid of curved reflecting surfaces to concentrate the rays. It generally consists of a metal plate painted black on the side that faces the sun, but many other forms are available.

Flux (Solar flux) The amount of solar energy per unit of time (or power) flowing across a given area. Often imprecisely used to refer to irradiance (watts/m^2) or total incident insolation (Joules/m^2 or kilowatt hours/m^2).

FOB Free on board. An economic convention for specifying the cost of hardware at the factory, but not including transportation charges.

Fossil fuel Combustible matter formed from the deposition of organic materials over time.

FPC See Federal Power Commission.

Fresnel lens (Circular) A disk of flat plastic or glass into which grooves have been cut in such a pattern that light energy will be concentrated on a point. (Linear) Indefinite length, longitudinal grooves, concentration on a line. Fresnel mirrors are also available.

Fuel saver A solar device which is used solely to save fuel at conventional fossil fuel-burning facilities. The conventional systems provide the needed system reliability.

Fuels From Biomass A major solar subprogram within the Department of Energy, Division of Energy Technology, responsible for research, development, and demonstration of a wide range of energy technologies which originate with biomass materials.

FY Fiscal year of federal government (July through June before 1976; October through September after 1976); a three-month transition quarter (TQ) occurred in 1976.

GAC General Advisory Committee, a special advisory group in the AEC and ERDA. With the formation of the Department of Energy, it became known as the Solar Working Group as it finished its last assignment.

GAO See General Accounting Office.

Gasifier Device which generates from organic residues a low-energy gas which can substitute for gas and oil in existing equipment.

Gasohol A fuel composed of gasoline and alcohol.

General Accounting Office A Congressional organization with broad investigatory powers which has produced numerous solar reports.

General Services Administration The principal "landlord" of the federal government with past, present, and future responsibility for installing solar units for many other federal agencies.

Geothermal energy Energy produced by the exploitation of the internal heat of the earth.

GFL A simple design method for sizing solar energy space and water heating systems (designed at the Solar Energy Research Institute).

Gigawatt Power unit equal to one billion (10^9) watts, one thousand megawatts, or one million kilowatts.

Glauber's salt Sodium sulfate decahydrate ($Na_2SO_4 \cdot 10 H_2O$), a hydrated salt that melts at 90°F and absorbs about 104 Btu per pound as it does so.

Global radiation Sum of diffuse and direct insolation (watts/m^2). See total insolation.

GNP See Gross National Product.

Greenhouse effect The trapping of energy with a consequential rise in temperature due to a multiplicity of causes, such as reduced convection or reflection, increased absorption, etc. Used to describe the basis for the intentional rise in solar collectors, as well as the Earth's possible temperature rise due to increasing carbon dioxide content in the atmosphere.

Gross National Product A national economic measure often related to energy consumption with implications for solar policy.

GSA See General Services Administration.

GSO Geostationary orbit.

H_2 Hydrogen gas.

Head The distance in units of meters, feet, etc., from the surface of the water behind a dam to the turbine of a hydroelectric plant. (See hydroelectricity.)

Heat exchanger A device used to transfer heat from a fluid flowing on one side of a barrier to a fluid or fluids flowing on the other side.

Heating degree day One day with the average ambient temperature one degree cooler than 65°F.

Heat of fusion The heat released when a liquid freezes. It is equal to the amount of heat absorbed when the solid melts.

Heat pipe A heat-transfer device consisting of a cylinder or tube which absorbs heat by vaporization of a liquid at one end and releases heat by condensation of vapor at the other end.

Heat pump An engine that transfers heat from a relatively low-temperature reservoir to one at a higher temperature, the heat sink.

Heat sink Any device by means of which heat is removed from a thermal system. A medium or container to which heat flows.

Heliostat An instrument in which a reflective surface is mechanically moved so that sunlight is reflected in a constant direction to a receiver.

High head Refers to generation of hydroelectric power using large dams.

High-low emitter cell Normal solar cell with extra doping.

HLE cell See high-low emitter cell.

HUD See Department of Housing and Urban Development.

Hybrid system A combination of a solar technology with a conventional technology to provide the controlled availability needed for everyday use.

Hydroelectricity The conversion of the kinetic energy in moving water (generally first held behind a dam) to mechanical (rotary) energy and then to electricity by a generator. Sometimes considered a solar technology, the development of the potential of small dams is the responsibility of the

	Geothermal Division of the Department of Energy.
Hydrogenase	An enzyme of various microorganisms that promotes the formation of gaseous hydrogen.
Hydrolysis	Decomposition of a chemical compound by reaction with water. For example, starch and cellulose can be hydrolyzed by acids and enzymes to produce simple sugars which can be fermented to produce ethanol.
Hydrostorage	Technique to store power utilizing a dam by pumping water into a reservoir, to be drawn out when power needs to be generated.
IAEA	International Atomic Energy Agency, Vienna, Austria.
IBC cell	Interdigitated back contact photovoltaic cell.
IEA	International Energy Agency, Paris, France.
IEEE	See Institute of Electrical and Electronics Engineers.
Incident Angle	The angle between the incident ray from the sun and a line drawn normal to the solar collector surface.
Industrial process heat	The end-use applications of thermal energy in industry covering a wide range of temperatures. The term is also used to indicate that portion of the national solar program which deals with this end-use. See AIPH.
Infiltration	Uncontrolled air leakage into or out of a building.
Infrared	Invisible long wavelength radiation (heat); also capable of producing a thermal or photovoltaic effect, though less effective than visible light.
In situ	In (the original or natural place).
Insolation	The solar power density incident on a surface of stated orientation, usually measured in watts/m^2 or Btu/ft^2/hr. This implies total insolation which is the sum of diffuse and direct components.
Institute of Electrical and Electronics Engineers	A major professional organization for publishing literature and standards on a wide range of electric generating devices.
Interagency Panel on Terrestrial Applications of Solar Energy	A federal, all-agency group that meets monthly to exchange information.
Intermediate plant	An electrical plant which is used to meet daily or seasonal variations in electrical load. The annual average use of this type of plant is less than that of base load plants, but more than peak load plants.
International Solar Energy Society	The principal worldwide organization for exchanging technical information on all forms of solar energy. United States headquarters are located at Killeen, Texas. The international headquarters' mailing address is PO Box 52, Parkville, Victoria, Australia 3052.
IPH	See industrial process heat.
IPTASE	See Interagency Panel on Terrestrial Application of Solar Energy.
Irradiance	Radiant flux density. The amount of radiant power per unit area that flows across or onto a surface.
ISES	See International Solar Energy Society.
Isotropic distribution	Approximation (when referring to diffuse radiant energy fluxes from the sky) in which the radiance of the sky is taken to be independent of position in the sky.
Jet Propulsion Laboratory	Operated for the National Aeronautics and Space Administration by the California Institute of Technology and located in Pasadena, California. Responsible for solar work in both photovoltaics and solar thermal areas.
Joule	Unit of energy; work done when a force of one Newton is displaced though a distance of one meter.
JPL	See Jet Propulsion Laboratory.
kW	Kilowatt. The international unit of power (or energy per unit time) equal to one thousand watts.
kWh	Kilowatt-hour. An international unit of energy equal to one thousand watt-hours.
L-5	A special gravitationally stable location between the Earth and the moon, suitable for maintenance of a permanent space colony; L stands for Lagrangian.
Labor-intensive	Indicates that a relatively large percentage of costs are labor-related.
Langley	Unit of solar radiation intensity equivalent to 1.0 gram calorie per square centimeter.
LASL	See Los Alamos Scientific Laboratory. Also a design model developed there.

Latitude — The angular distance north (+) or south (−) of the equator, measured in degrees.

LDC — Less developed country.

Learning curve — The ability of manufacturers to reduce the unit cost of a given "item" as total production volume accumulates. A product is said to be on an 80% learning curve if the cost of the product drops 20% with a doubling of cumulative production.

Lewis Research Center — Part of the National Aeronautics and Space Administration, located near Cleveland, Ohio. Responsible for work in photovoltaics, wind, and storage areas.

Life-cycle cost — A measure of what something will cost totally, not only to buy but also to operate over its lifespan. The accumulation generally includes a discounting of future costs to reflect the relative value of money over time.

Liquified natural gas — Transporting liquified natural gas from overseas at very low temperatures is proposed as an alternative to solar deployment.

LNG — See liquified natural gas.

Load-leveling — Technique for smoothing a power profile of a customer or an entire utility over a period of time; this usually requires constraints on power usage (shift usage). Solar devices with storage have a load-leveling potential.

Local apparent time (LAT) — System of astronomical time, in which the sun always crosses true north-south meridian at 12 noon. This system of time differs from local time according to longitude and time zone. The precise displacement also varies with the time of year.

Los Alamos Scientific Laboratory — Operated by the University of California for the Department of Energy. Has a major program in passive solar development.

Low head — Refers to generation of hydroelectric power with relatively small dams.

LRC — See Lewis Research Center.

Magnetohydrodynamic generation — The generation of electricity from the interaction of a strong magnetic field with the motion of an electrically charged fluid, such as high-temperature ionized gas.

Market penetration — How much of a product will be sold on a yearly basis as it gains consumer acceptability over a specified time.

MBtu — Million (10^6) Btu. The predominant unit of energy in the United States. Generally, one million Btu are worth between $1 and $10. Frequently written MMBtu.

Megawatt — Power unit equal to one million watts or one thousand kilowatts.

Metal insulator semiconductor — A barrier type of photovoltaic cell designed for lower cost, with successive layers of semiconductor, insulator, and metal.

Methane — A colorless, odorless, flammable gas, CH_4, that is the product of decomposition of organic matter (or the gasification of coal). It forms the major portion of marsh gas and natural gas.

Methanol — A light, volatile, flammable, poisonous, liquid alcohol, CH_3OH, formed in the destructive distillation of wood (or made synthetically).

Microorganism — An organism of microscopic size. Used in anaerobic digestion.

MIS — See metal insulator semiconductor.

MITRE/METREK — The METREK Division of the MITRE Corporation, located in McLean, Virginia, is a nonprofit firm which has received funding from numerous sources to perform a comparable analysis and market impact of solar energy. Often coupled with acronym SPURR.

MJ — Energy unit equal to one million joules.

Module — The smallest, complete, environmentally protected assembly of solar cells, optics, and other components designed to generate DC power.

MOPPS — Market Oriented Program Planning Study. A 1977 energy analysis developed for ERDA to simultaneously compare and project all ERDA energy technologies.

MW — See megawatt.

MWh — Megawatt-hour. Energy unit equal to one million watt-hours or one thousand kilowatt-hours.

NASA — National Aeronautics and Space Administration.

National Energy Plan — The Presidential energy message given to Congress on April 20, 1977. The enactment of the National Energy Plan by Congress will be known as the National Energy Act.

National Oceanic and Atmospheric Administration — Part of the Department of Commerce. Has responsibility for 35 sites comprising the national insolation monitoring network.

National Science Foundation The principal research organization of the federal government. Had responsibility for the national solar program until 1974, when the Energy Research and Development Administration was formed.

NBS National Bureau of Standards.

NCAT National Center for Appropriate Technology, funded by CSA and located in Butte, Montana.

NEA National Energy Act.

NEMA National Equipment Manufacturers Association.

NEP See National Energy Plan.

NOAA See National Oceanic and Atmospheric Administration.

NSF See National Science Foundation.

Nuclear Power Satellite System Similar to photovoltaic or solar thermal satellite power systems in beaming microwave energy back to Earth from space for rectification and conversion, but starting with electricity generated by a nuclear reactor.

OEDC See Organization for Economic Cooperation and Development.

Office of Energy Research A part of the Department of Energy responsible for basic research with energy applications; a portion of its activities is solar related.

Office of Management and the Budget Reports to the President. Has final authority in recommendations of all budgets to Congress.

Office of Technology Assessment An analysis organization reporting to the Congress. Has prepared several solar energy reports and a major study on on-site solar electricity.

Office of the Assistant Secretary for Energy Technology In the Department of Energy; responsible for the development of numerous energy technologies, including all solar electric and biomass technologies.

Off-peak Refers to periods of low electricity demand; e.g., late evening.

Ohm-cm The units of electrical resistivity; an important parameter for semiconductors used in photovoltaic devices.

OMB See Office of Management and the Budget.

OPEC Organization of Petroleum Exporting Countries.

Open-cycle ocean thermal energy See also closed-cycle ocean thermal energy conversion. Here, the OTEC working fluid is ocean water which itself is vaporized.

Organization for Economic Cooperation and Development Members—the nations of western Europe, the United States, and Japan—support several solar programs.

OTA See Office of Technology Assessment.

OTEC Ocean thermal energy conversion. The use of temperature differentials between warm (upper) and cold (deeper) levels of the ocean to drive a low-pressure turbine connected to a generator to produce electricity or shaft power.

Panel A group of modules fastened together, preassembled and wired, designed to serve as an installable unit in an array.

Parabolic trough A trough-shaped, mirroring device focusing along a line, and used for concentration ratios less than about 100.

Paraboloidal dish A parabolic-shaped device covered with a highly reflective or mirrored surface with focus at a single point; used in solar concentrators with concentration ratios typically from 1,000 to 10,000.

Passive system A solar heating or cooling system that uses conductive, convective, or radiative mechanisms (i.e., no external mechanical power) to move the collected solar heat.

Payback A traditional measure of economic viability of investment projects. A payback period is defined in several ways—one of which is the number of years required to accumulate fuel savings which exactly equal the initial capital cost of the system. Payback often does not give an accurate representation of total life-cycle value.

Peak watt A measurement unit used for performance rating of solar panels and arrays. A panel rated at 1 peak watt will deliver 1 watt under specified standard operating conditions with a solar insolation of 10^3 W/m^2.

Phase change The change from one solid, liquid, or gaseous state to another. Associated with such a change of state is a large energy input (or release), known as the heat of fusion or vaporization.

Phonon A quantum of thermal vibration in a crystal lattice.

Photobiology The branch of biology concerned with the study of the interactions of light with biological systems. An example is the study of photosynthesis.

Photochemistry The branch of chemistry concerned with the study of chemical reactions initiated by interactions of light with matter.

Photo-conversion Conversion of light into other forms of energy by chemical, biological or physical processes.

Photoelectro-chemistry The branch of chemistry concerned with the study of oxidation and reduction reactions initiated by visible, ultraviolet, or near-infrared radiation at the surface of a photovoltaic device immersed in a conducting solution.

Photo-electrolysis The use of photoelectrochemical cell to produce hydrogen and oxygen from water. See photoelectrochemistry.

Photolysis A chemical process initiated by light, in which molecular bonds are made or broken.

Photon A massless particle, the quantum of the electromagnetic field carrying energy, momentum, and angular momentum.

Photophysical processes Physical processes following the absorption of light after which there is no change in chemical bonds. Such events usually take place in the femtosecond (10^{-15}s) to nanosecond (10^{-9}s) time region.

Photosensitize To make sensitive to light.

Photosynthesis The process by which chlorophyll-containing cells in green plants convert incident light to chemical energy and synthesize organic components from inorganic components.

Photothermal conversion The conversion of light to thermal energy.

Photovoltaic A solid-state electrical device whose current voltage chartacteristic is a function of the incident radiation; capable of producing an electric power when exposed to radiant energy, especially sunlight.

Photovoltaic system An installed aggregate of solar arrays and other subsystems transmitting power to a given application.

Polycrystalline silicon Silicon consisting of many small, randomly arranged crystals. When used in solar cells, it offers the promise of lower cost.

Power tower A tower placed so that the reflected direct radiation from heliostat mirrors can be focused onto a receiver at its top. heat exchange takes place at the top of the tower and the heated fluid is used in a conventional power system.

Primary energy Fuels as they are extracted from their original sources; i.e., fuels not derived from other fuels (coal, oil, and natural gas, for example).

Process heat Thermal energy which is used in agricultural and industrial operations.

Projection An estimation of probable future events.

PUC Public Utility Commission.

Pyranometer A solar radiometer which measures total insolation or global radiation—both diffuse and direct components (watts/m^2).

Pyrheliometer A solar radiometer used to measure only the direct solar insolation (watts/m^2).

Pyrolysis Decomposition of organic material into chemical constituents by the action of heat.

Quad Quadrillion (10^{15}) Btu. Commonly used as measure of annual energy consumption, usually expressed as primary fuel equivalent. Present U.S. consumption is about 75 Quads.

Radiometer Instrument measuring the intensity of any kind of radiation.

Rankine engine Heat engine using various components, including a working fluid pumped under pressure to a boiler where heat is added; an expander (turbine) where work is generated; and a condenser used to reject low-grade heat to the environment. A steam engine is a Rankine engine.

R&D Research and development.

RD&D Research, development, and demonstration.

Receiver The component designed to operate under concentrated sunlight, incorporating the concentrator cell assembly and providing thermal energy removal.

Recombination loss Energy loss which occurs when electron-hole pairs recombine without contributing photovoltaically.

Rectenna A device that converts microwave energy into direct current power; consists of a number of small dipoles, each having its own diode rectifier network, which are connected to direct-current buses.

Redox Abbreviation for reduction-oxidation.

Redox battery In this battery, the electrolytes in the anode and/or cathode compartments contain ions of metals which can exist in more than one valence state. At the anode such a redox couple is oxidized, while another couple is reduced at the cathode.

Reflectance The ratio of radiation reflected from a surface to that incident on the surface. Reflectivity is the property of reflecting radiation posssessed by all materials to varying extents, sometimes called the albedo in atmospheric references.

Regenerative cooling system Cooling system operated by using a charging and discharging cycle with a thermal or latent heat storage device.

Renewable resources Sources of energy that are regenerative or virtually inexhaustible, such as solar energy.

Reradiation The transfer or loss of energy by radiation of thermal energy from a prior absorption of energy. Often, the reradiation energy is at a longer wavelength than the absorbed energy, which allows for control of this transfer.

Resistance The tendency of a material to retard the flow of heat. Often called R-value.

Retrofit To fit solar collectors to existing buildings, or more generally, any additon of a new technology to an existing structure.

RFP Request for Proposal; the formal solicitation of proposals to contract for a specific scope of work.

Roll bond process Bonding sheets of metal together by simultaneously rolling and using and using a heat treatment.

Roof pond A passive solar collection system in which plastic bags of water on the roof are appropriately exposed or insulated during the day and night depending on the thermal requirements of the building for summer and winter operation. Heat transfer (in to or out of the bags) to the structure is directly through the ceiling.

R-value See resistance.

SAE Society of Automotive Engineers.

Scenario A set of projections used as an assumption to conduct future planning. See also simulation.

scf Standard cubic feet. (As in Btu/scf gas.) The volume of a gas at standard sea level atmospheric pressure and a temperature of 60°F.

SEIA See Solar Energy Industries Association.

SEIDB See Solar Energy Information Data Bank.

Selective absorber A surface which has high absorptance at wavelengths corresponding to the solar spectrum and low emittance in the infrared range.

Semiconductor A crystalline material whose atomic structure is such that it has an electrical conductivity intermediate between an insulator and a metal. Its conductivity can be greatly influenced by the addition of doping agents. The doped semiconductor can have either an excess of energy-conducting electrons (n-type) or a deficiency of them (p-type).

Sensible heat Refers to storage of thermal energy through only a change in temperature of a substance (not a phase change). Examples of storage materials are water and rock.

SEO State Energy Office.

SERI Solar Energy Research Institute, a division of Midwest Research Institute, Kansas City, Missouri; funded by the Department of Energy and located in Golden, Colorado.

SHACOB Solar Heating and Cooling of Buildings. Both the process and the name of one of the major budget categories in the Department of Energy's solar program.

Silviculture The cultivation of forest trees; forestry.

SIMSHAC Solar heating and cooling design model.

Simulation The use of mathematical representations of real systems to determine what is likely to happen under various possible sets of conditions.

SNG See synthetic natural gas.

SO_2 Sulfur dioxide.

Solar cell The basic photovoltaic device which generates electricity when exposed to sunlight.

Solar collector A structure which collects and converts the sun's radiation into a more useful energy form.

Solar constant The intensity of solar radiation beyond the Earth's atmosphere, at the average Earth-sun distance, on a surface perpendicular to the sun's rays. The value for the solar constant is 1,353 W/m^2, 1.940 cal/cm^2-min, or 429.2 $Btu/ft^2/hr$ ($\pm$ 1.6%).

Solar Energy Industries Association Organization of manufacturers of solar devices, primarily for heating and cooling of buildings, headquartered in Washington, D.C.

Solar Energy Information Data Bank A comprehensive solar energy information data bank providing a solar energy library and a variety of solar energy information files. It will also provide the capability of executing computer programs for scientific computations and for solar energy simulations. Mandated by law, it is located at the Solar Energy Research Institute in Golden, Colorado.

Solar pond A pond with a blackened base containing (stratified) brackish water and used to collect and store solar heat.

Solar Power Satellite A proposed satellite in geosynchronous orbit (22,000 miles) to convert solar energy to electricity and then to microwave energy, which is beamed to Earth for later conversion to direct current electricity.

Solar rights Refers to the legal question regarding the right of a person who uses a solar energy device not to have his sunlight blocked by another structure.

Solar thermal conversion The conversion of thermal energy (starting from solar energy) to electricity using various heat engines, e.g. the power tower or small decentralized receivers with Brayton engine cycles, Stirling engine cycles, etc.

Solar Total Energy System A system of solar (photovoltaic or solar thermal) production of electricity with the use of the "waste" heat for such thermal applications as heat, hot water, and absorption air conditioning.

Solar Working Group The group, no longer in existence and previously named the General Advisory Council, was concerned with the balance among several solar technologies and the relative amount of resources and attention each received.

SOLCOST A computerized design method developed by Martin Marietta Corp. for predicting performance of residential and light commercial solar heating and cooling systems.

SOLDAY A meteorological data base containing daily values for meteorological and solar radiation values. Available from the National Climatic Center.

SOLMET A meteorological data base containing hourly values for meteorological and solar radiation values. Available from the National Climatic Center.

Spectral energy distribution A curve showing the variation of spectral irradiance with wavelength.

Spectral irradiance The monochromatic irradiance of a surface per unit bandwidth at a particular wavelength. Units often watts/m^2-nanometer bandwidth.

Specular reflection Mirror-like reflection; incident and reflected angles are equal.

SPS See Solar Power Satellite. Also used to refer to Small Power Systems, usually implying a ground-based solar thermal approach. Also Space Power Systems.

SPURR See System for Projecting the Utilization of Renewable Resources, and MITRE/METREK.

SSPS Space Solar Power Systems. See Solar Power Satellite.

ST See Solar thermal conversion.

STES Solar Total Energy System.

Stirling engine Hot-air external combustion or heat engine, usually with a regenerator that prevents dissipation of heat between cycles.

STOLAR A random event solar system simulation model used by architects.

Stratification (thermal) Process used in solar thermal storage systems whereby hot water (being less dense) floats on the top of more dense cold water.

Suns A dimensionless measure of the intensity of solar energy based on the amount of energy received from the sun (one sun) following its concentration by lenses or mirrors. Concentration ratios exceeding 10,000 suns have been achieved.

Superconductor A substance (metals, alloys, and compounds) exhibiting superconductivity; i.e., the disappearance or near disappearance of the electrical resistance of certain materials at temperatures below a transition zone (usually a few degrees above absolute zero). One of the main applications is to the production of electromagnets.

SWECS — Small Wind Energy Conversion Systems. See Wind Energy Conversion Systems.

SWG — See Solar Working Group.

Synthetic natural gas — A manufactured gas comprised chiefly of methane and roughly equivalent in heating value to natural gas. Synthetic natural gas can be synthesized from biomass or coal.

System for Projecting the Utilization of Renewable Resources — SPURR—a major solar penetration model. See MITRE/METREK.

Technical fix — The use of technical solutions to problems which might be solved through institutional or behavioral changes. Sometimes used in a derogatory manner.

Technocracy — A government or social system managed by "technicians" or a technically trained elite.

Technology — The application of knowledge for practical purposes; for example, engineering designs to convert solar energy into more useful forms of energy such as electricity or space heating.

Tennessee Valley Authority — A major, potential federal purchaser of solar systems, already active in experiments.

Terawatt — Power unit equal to 10^{12} watts or one million megawatts; TW.

TES — See total energy system.

Thermal capacitance — The ratio of the amount of heat added to the resulting rise in temperature in a unit mass of material, often called specific heat. Btu per pound per degree F.

Thermal conversion — The transformation of heat into other forms of energy such as electricity or shaft power. Heat may be supplied from the sun either directly (solar collector) or indirectly (biomass).

Thermal mass — Also thermal inertia. The tendency of a building with large quantities of heavy materials to remain at the same temperature or to fluctuate only very slowly; also, the overall heat storage capacity of a building.

Thermionic engine — A conversion device in which electrical energy is produced directly from heat energy by the conversion of heat into electricity via boiling electrons from a hot metal surface and condensing them on a cooler surface.

Thermochemical dissociation — A process for generating storable chemicals by using the sun's energy in a (sometimes complex) chemical reaction. A possible reaction could produce hydrogen and oxygen from water, using only a high-temperature, solar-driven, chemical reaction.

Thermo-conversion — The transformation of organic matter into other forms of energy such as electricity or fuels using heat. See bioconversion.

Thermosyphon system — System with natural thermal circulation—normally referring to water—in which hot water rises to the top of the system, displacing the colder water to a lowest point of the system. A heat exchanger in which the circulation of the working fluid is achieved by convection.

Tons of Cooling — One standard commercial ton of refrigeration is defined as 288,000 Btu absorbed at a uniform rate during 24 hours.

Total energy system — The productive use of thermal "waste" energy resulting from any electrical production process. Also see Solar Total Energy System.

Total insolation — The sum of direct and diffuse insolation.

Transmittance — The ratio of the radiant energy transmitted by the parallel-sided planar surface of a given material to the radiant energy incident on the upper surface of that material; it depends on the angle of incidence.

Trickle-type collector — A collector in which the heat transfer liquid flows down channels in the front face of the absorber.

TRNSYS — Transient solar system simulation program which is useful as a research tool; a dynamic solar system simulation.

Trombe wall — A passive solar collection system named after its inventor (a Frenchman), Felix Trombe, which incorporates a transparent heat retaining surface (glass or plastic) on the outside of a darkened wall. Warm air rising between the two surfaces can be ducted inside or outside depending on the thermal requirements of the structure.

Turbidity — Atmospheric haze owing to aerosols and particulates.

TVA — See Tennessee Valley Authority.

TW — See terawatt.

U Overall heat transfer coefficient; frequently called the U-value.

USDA United States Department of Agriculture. See Department of Agriculture.

U-value See coefficient of heat transmission.

WAES Workshop on Alternative Energy Strategies. A study performed at MIT.

WECS See Wind Energy Conversion Systems.

Wh/kg Watt-hours per kilogram.

Wind Energy Conversion Systems Any technology for converting the energy in wind streams into useful forms of energy. Also, the Department of Energy solar branch and program responsible for federal expenditures in this area.

W/kg Watts per kilogram.

W_p See peak watt.

WTG Wind turbine generator.

Chemical Elements

Actinium (Ac)
Aluminum (Al)
Americium (Am)
Antimony (Sb)
Argon (Ar)
Arsenic (As)
Astatine (At)
Barium (Ba)
Berkelium (Bk)
Beryllium (Be)
Bismuth (Bi)
Boron (B)
Bromine (Br)
Cadmium (Cd)
Calcium (Ca)
Californium (Cf)
Carbon (C)
Cerium (Ce)
Cesium (Cs)
Chlorine (Cl)
Chromium (Cr)
Cobalt (Co)
Columbium (Cb)
Copper (Cu)
Curium (Cm)
Dysprosium (Dy)
Einsteinium (Es)
Erbium (Er)
Europium (Eu)
Fermium (Fm)
Fluorine (F)
Francium (Fr)
Gadolinium (Gd)
Gallium (Ga)
Germanium (Ge)
Gold (Au)
Hafnium (Hf)
Helium (He)
Holmium (Ho)
Hydrogen (H)
Indium (In)
Iodine (I)
Iridium (Ir)
Iron (Fe)
Krypton (Kr)
Lanthanum (La)
Lawrencium (Lr)
Lead (Pb)
Lithium (Li)
Lutetium (Lu)
Magnesium (Mg)
Manganese (Mn)
Mendelevium (Md)
Mercury (Hg)
Molybdenum (Mo)
Neodynium (Nd)
Neon (Ne)
Neptunium (Np)
Nickel (Ni)
Niobium (Nb)
Nitrogen (N)
Nobelium (No)
Osmium (Os)
Oxygen (O)
Palladium (Pd)
Phosphorus (P)
Platinum (Pt)
Plutonium (Pu)
Polonium (Po)
Potassium (K)
Praseodymium (Pr)
Promethium (Pm)
Protactinium (Pa)
Radium (Ra)
Radon (Rn)
Rhenium (Re)
Rhodium (Rh)
Rubidium (Rb)
Ruthenium (Ru)
Samarium (Sm)
Scandium (Sc)
Selenium (Se)
Silicon (Si)
Silver (Ag)
Sodium (Na)
Strontium (Sr)
Sulfur (S)
Tantalum (Ta)
Technetium (Tc)
Tellurium (Te)
Terbium (Tb)
Thallium (Tl)
Thorium (Th)
Thulium (Tm)
Tin (Sn)
Titanium (Ti)
Tungsten (W)
Uranium (U)
Vanadium (V)
Xenon (Xe)
Ytterbium (Yb)
Yttrium (Y)
Zinc (Zn)
Zirconium (Zr)

APPENDIX 3

CONVERSION FACTORS

To Change	Into	Multiply By
acres	ft^2	43,560
acres	m^2	4,047
atmospheres	cm of mercury	76.0
atmospheres	lb inch $^{-2}$	14.7
Btu	cal	252
Btu	joules	1,055
Btu	kcal	0.252
Btu	kWh	2.93×10^{-4}
Btu ft^{-2}	langleys (cal cm^{-2})	0.271
cal	Btu	3.97×10^{-8}
cal	ft-lb	3.09
cal	joules	4.184
cal	kcal	0.001
cal min^{-1}	watts	0.0698
cm	inches	0.394
cc or cm^3	$inches^3$	0.061
ft^3	liters	28.3
$inches^3$	cc or cm^3	16.4
ft	inches	12
ft	m	0.305
ft-lb	cal	0.324
ft-lb	joules	1.36
ft-lb	kg-m	0.138
ft-lb	kWh	3.77×10^{-7}
gal	liters	3.79
gal	qt	4.00
g	lb	0.0022
hectares	acres	2.47
hp	kWw	0.745
inches	cm	2.54
joules	Btu	9.48×10^{-4}
joules	cal	0.239
joules	ft-lb	0.738
kcal	Btu	3.97
kcal	cal	1,000
kcal min^{-1}	kW	0.0698
kg-m	ft-lb	7.23
kg	lb	2.20
kg	tons	0.0011
kW	hp	1.34
kWh	Btu	3,413
kWh	ft-lb	2.66×10^{8}
kW	kcal min^{-1}	14.3
langleys (cal cm^{-2})	Btu ft^{-2}	3.69

To Change	Into	Multiply By
langleys min $^{-1}$ (cal cm^{-2} min^{-1})	watts cm^{-2}	0.0698
liters	gal	0.264
liters	qt	1.06
m	ft	3.28
m	cm	100
m	inches	39.4
m	miles	6.21×10^{4}
miles	ft	5,280
miles	m	1,609
lb	g	454
lb	kg	0.454
lb $inches^{-2}$	atmospheres	0.068
qt	liters	0.946
cm^2	ft^2	0.00108
cm^2	$inches^2$	0.155
ft^2	cm^2	929
ft^2	$inches^2$	144
ft^2	m^2	0.0929
$inches^2$	cm^2	6.45
m^2	ft^2	10.8
m^2	$miles^2$	3.86×10^{-7}
$miles^2$	acres	640
$miles^2$	ft^2	2.79×10^{7}
$miles^2$	m^2	2.59×10^{6}
tons	kg	907
tons	lb	2,000
watts cm^{-2}	langleys (cal cm^2) min^{-1}	14.3
yd	ft	3
yd	cm	91.4
°Fahrenheit	°Centigrade	subtract 32 and multiply by 5/9 or 0.555
°Centigrade	°Fahrenheit	multiply by 9/5 or 1.8 and add 32
°Kelvin	°Centigrade	subtract 273.16
cal cm^{-2} $\cdot sec^{-1}$ $°C^{-1}$	Btu ft^{-2} hr^{-1} $\cdot °F^{1}$	7,380
Btu ft^{-2} $\cdot hr^{-1}$ $\cdot °F^{-1}$	cal cm^{-2} $\cdot sec^{-2}$ $\cdot °C^{-1}$	0.000135

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