JPL-5103-56
Solar Thermal Power Systems
Point-Focusing
Thermal and Electric Applications Project

Perspectives on the Dispersed Application of Solar Thermal Energy Technology

Volume I: Executive Summary

April 15, 1979

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U.S. Department of Energy
Through an agreement with
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T.J. Kuehn
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The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy and forms a part of the Solar Thermal Program to develop low-cost solar thermal electric generating plants.

ABSTRACT

This report presents an overview of the technological, economic, and institutional issues which affect the development and market acceptance of dispersed solar thermal power. The first set of working papers (Volume II) analyzes the problems involved in making solar thermal energy a viable alternative. Section I introduces the volume. Sections II and III survey the system concepts and components currently under study and include information on recent cost and performance estimates. Section IV examines trends in national energy demand and supply and evaluates the implications of these trends for dispersed power systems. The next two sections (V and VI) focus on more quantitative subjects--financial factors affecting the cost of solar power to users and market penetration analysis--which will be analyzed in more detail in later documents. Regional variations of the solar resource are discussed in Section VII, and the final section (VIII) compiles a research agenda for dispersed solar thermal systems.

Volume III continues the analysis of dispersed solar thermal power systems begun in Volume II. It focuses on the market environment which will confront solar thermal power systems. It attempts to better understand market operation in order to more efficiently introduce and diffuse alternative energy sources into the marketplace. Section IX is an introduction to this volume. Section X focuses on the firms involved in carrying out the adoption process; it surveys the operations within the production process, assesses the potential for cost reduction through mass-production techniques, and identifies production systems which might facilitate the industrial development of solar thermal power. Next, Section XI investigates barriers to the market acceptance of solar thermal power. These include a lack of emphasis on analysis of market conditions, limited user involvement in federal innovation efforts, and a tendency for prolonged federal development to compete with private efforts. Section XII analyzes the prospects for expediting the adoption of solar thermal power systems; it describes the key factors which must be considered in formulating federal commercialization programs, and develops a set of specific recommendations for enhancing interactions with private industry. The final section (XIII) summarizes these efforts and compiles a recommended research agenda for dispersed solar thermal power systems.

FOREWORD

This report is organized into three volumes: Volume I - Executive Summary; Volume II - Working Papers on Technical, Economic and Solar Resources Issues, and Volume III - Working Papers on Commercialization and Industrialization. These working papers provide an overview of the issues and problems of solar thermal technology development and application. Several of the papers are intended to inform the public and energy policy-makers about the general principles of solar thermal energy production and to define the economic, political and institutional problems that must be solved in order to exploit the solar thermal resource. Other technical papers address the analytical problems that must be solved in order to provide better information for decision-making regarding the development and use of solar thermal energy.

These working papers represent the status of work in progress. They initiate a research effort to improve the methods used to predict and evaluate the resources, costs, markets, and impacts associated with solar thermal energy. This information is important because the viability of solar power is contingent not only upon the development of new hardware, but also upon knowledge of the complex interactions between supply and demand for this new technology.

This report also indicates the need for social and scientific analyses of solar power issues in order to reduce the uncertainty that presently exists throughout the research, development, and demonstration processes. This report identifies the problems and issues confronting solar thermal energy today. This is the first step in the successful development of solar thermal technology.

ACKNOWLEDGMENTS

The authors of this report gratefully acknowledge the reviews presented by Richard Caputo, E. S. Davis, Martin Goldsmith, Alan Marriott, Richard O'Toole, and Christopher Stevens which have made a significant contribution to the publication of these working papers.

TABLE OF CONTENTS

Figures

Tables

SECTION I

INTRODUCTION

Rapidly rising energy prices and diminishing availability of traditional fuel sources have stimulated a search for alternative energy technology. One of these alternatives may be dispersed solar thermal power, which can provide high temperature (160° to 1400° C), environmentally clean heat and electricity in a wide variety of applications. However, there are a number of issues which must be resolved before solar thermal power becomes a fully developed alternative with commercial viability. Technological innovations and component cost reductions will enhance the competitive potential of solar thermal systems, but there are many other issues which affect the market acceptance of solar energy as well.

Some of the important technological, economic and environmental problems that must be solved before solar thermal power can become a viable, competitive alternative are identified and discussed in this report. Volume I provides a synthesis and overview of the working papers presented in Volumes II and III. These working papers provide a comprehensive look at a wide range of issues, suggest policies and research programs, and explore methods that may contribute to the development of solar thermal energy. The succeeding volumes provide a multi-disciplinary perspective on the development of solar energy; this Executive Summary synthesizes these different perspectives.

A central theme of this report is that uncertainty is the least measurable and most pervasive factor in the development of solar thermal power; it appears in the technology, costs, market demand estimates, environmental impacts, regulations, and future alternatives. Actions which could measure or reduce uncertainty would greatly clarify solar power's viability. Basic and applied research should include an analysis of the uncertainties that present the largest barriers to the development of solar thermal power and a description of actions that would effectively resolve these uncertainties. Some means of expressing variability in system factors (price, reliability, etc.) so as to reflect uncertainty should also be developed. Since market uncertainty is a prime factor restricting industrial investment in solar power, improved information (through market studies, technical demonstrations, manufacturing development) might alleviate this problem.

In the following sections, uncertainties about the technology, economic feasibility, market potential, and value of solar resources are discussed. Suggestions for reducing these uncertainties are also presented.

SECTION II

SOLAR THERMAL TECHNOLOGY

There are many problems associated with the development, design, cost, installation and manufacture of solar thermal power systems. Most of these problems are not well understood because solar thermal power plants have not progressed beyond the design and component testing stages at best. Thus, the most immediate problem is the development of solar thermal technology itself. The principles of solar thermal energy collection and conversion are discussed in Volume II, Section II, which notes that improvements in conversion efficiency could reduce collector area, with consequent reductions in capital cost and land use requirements. To allocate limited research and development (R&D) resources more effectively, there soon may be a need to select an optimal system (or set of most promising systems) upon which to focus research efforts; even a choice of criteria and trade-offs to be included in this selection process will be an important decision.

A second major problem with solar thermal systems are their relatively high capital cost; although this problem is not unique to solar thermal energy, cost reduction will be one of the most decisive factors in determining solar thermal viability. Section III of the working papers outlines those systems and subsystems with the greatest potential for cost reduction. Although potential does not guarantee cost reduction, and cost reductions do not guarantee competitiveness, a R&D strategy which emphasizes cost reduction and improved performance may promote solar thermal power's competitive viability.

The next four subsections of this Executive Summary provide an overview of solar thermal technology, system costs, design trade-offs, cost reduction requirements, and critical R&D issues. Since experimental results from developmental models of these systems will not be available in the near future, it is important to remember that artist's concepts and cost estimates should not be confused with technological progress or reality. Much engineering development will be required to achieve the projected costs and performance of solar thermal power plants; the research and development required will be very costly and involve calculated risks. A strategy for efficient allocation of scarce solar R&D resources requires information on the opportunities for technological breakthroughs matched with the requirements and market potential of solar thermal applications.

A. PRINCIPLES AND PRACTICE

Solar thermal power systems convert sunlight or insolation to a useful energy form by the intermediate conversion of sunlight to thermal energy (heat). The final energy products are typically electricity or heat, but may include mechanical or other forms of energy depending upon the needs of specific applications. As illustrated in Figure 2-1, solar thermal power systems are comprised of four major subsystems: the collector, power conversion, energy transport, and energy storage subsystems. The collector usually contains a concentrator and a receiver. The concentrator redirects and focuses sunlight on the receiver using mirrors or lenses. The receiver operates as a special heat exchanger which absorbs the light and converts it to heat. Power conversion subsystems convert the thermal energy into electricity. Usually, a heat engine coupled to an electric generator is used. The energy transport subsystem delivers energy from the collector to the other subsystems. Energy storage is used to enable continuous solar thermal power system operation during periods of solar blockage and non-daylight hours. Fossil fuels can be used as a substitute for storage in solar plants that are designed to operate with both conventional fuels and solar energy simultaneously. Although hybrid solar plants use high-quality fossil fuels, they may be more reliable and less costly than plants with dedicated energy storage subsystems which are very costly and will remain so in the foreseeable future. Overall, the market penetration of solar-fossil hybrid power plants may be much greater without dedicated storage because such plants are more reliable, more efficient, and utilize more of the available solar energy by avoiding storage losses.

There are a large number of systems that can be constructed from the different types of subsystems outlined in Sections II and III of the working papers (Volume II). Two general collector designs currently being examined are the distributed receiver and central receiver concepts as illustrated in Figures 2-2 and 2-3. Central receiver systems use a large field of sun-tracking mirrors (heliostats) which focus sunlight on a central receiver. Distributed receiver systems consist of a field of many smaller concentrator receiver modules. For these two systems, a trade-off exists between the mass-production costs of many small concentrator-receiver modules and the operational economies of scale provided by large central receivers. A further dimension which differentiates collector designs is the type of sun-tracking mechanism employed. Collectors may be fixed, one-axis tracking or two-axis tracking. Fixed collectors are usually flat-plate or low concentration devices producing low temperatures (150° to 300° F) and low system efficiencies (5% to 10%). One-axis systems employ higher concentration ratios coupled with linear receivers for higher temperatures (300° to 800° F) and higher efficiencies (10% to 18%). Two-axis collectors used in distributed and central receiver systems (Figures 2-2 and 2-3) provide point-focusing capabilities with high temperatures (800° to 2000° F) and the highest system efficiencies (estimated at 15% to 30% or better). The trade-off here is between the higher cost, greater complexity and increased performance of two-axis systems, versus the lower cost, greater simplicity and reduced performance of one-axis or fixed systems.

Power conversion subsystems may be either central or distributed. Central conversion involves the collection of thermal energy from the collector at one large, central engine-generator. Distributed power conversion involves many smaller heat engine-generators located near the

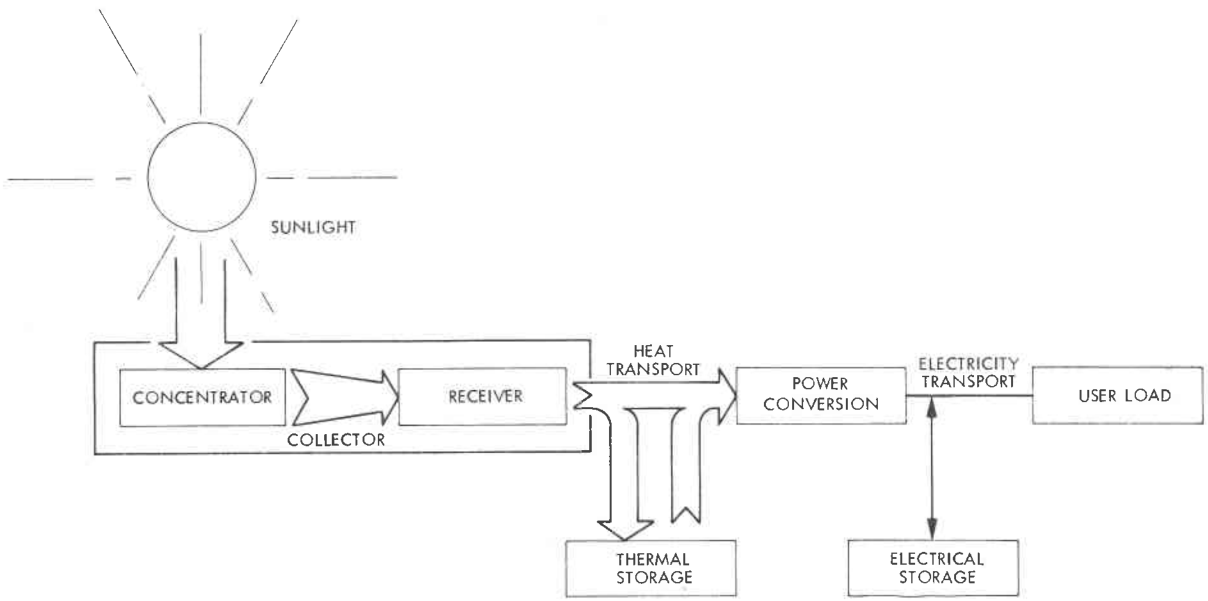
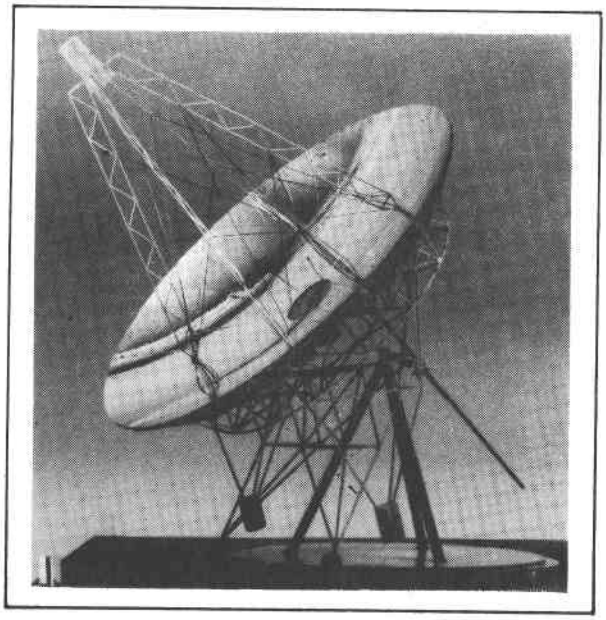


Figure 2-1. A Solar Thermal Electric Power System



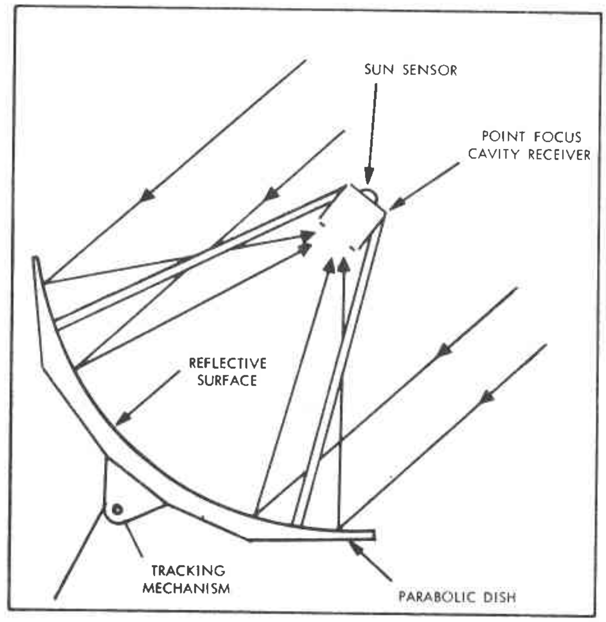
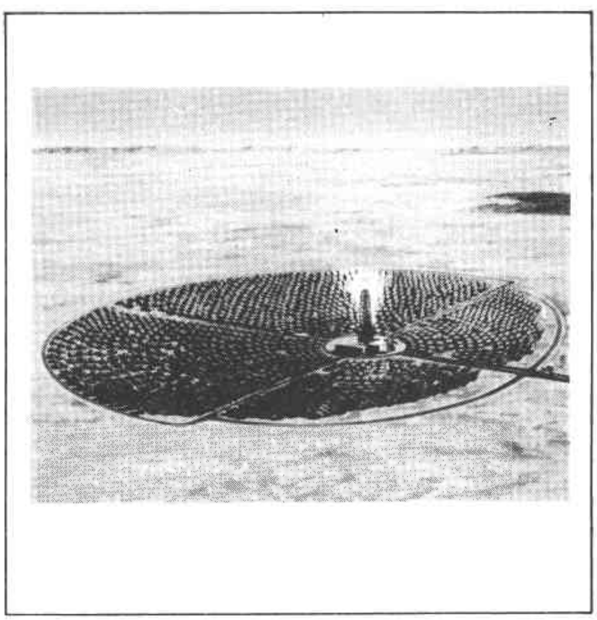


Figure 2-2. Small Parabolic Dish Collectors Using Distributed Receivers



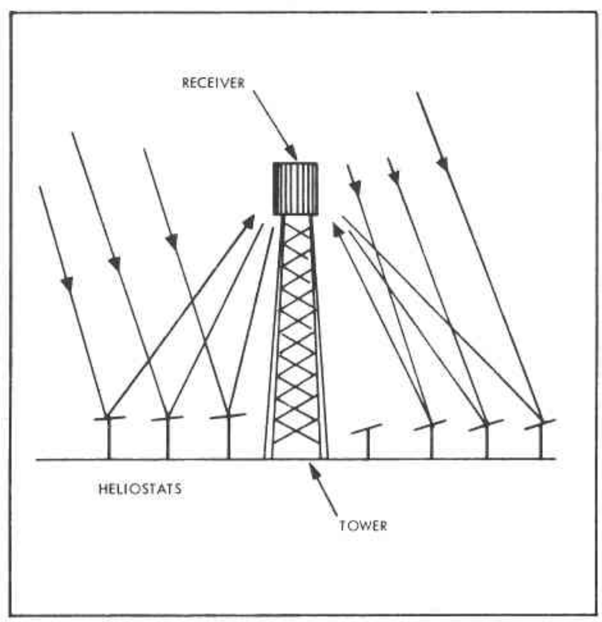


Figure 2-3. Large Heliostat Field Using Central Receivers

receivers. Naturally, distributed power conversion is only possible with distributed receiver systems. Distributed and central conversion configurations using point-focusing parabolic dishes and distributed receivers have been proposed for the PFTEA Project's first Engineering Experiment. Two of these proposed systems are illustrated in Figures 2-4 and 2-5. These, and one other proposed small power concept, the central receiver, are discussed in Volume II, Section III of this report. The major trade-off is between the cost reduction potential made possible by the mass production of many smaller units versus the operational economies of scale associated with using one large unit.

Another dimension of solar thermal power systems is the type of heat engine conversion cycle employed. The conversion cycles most often considered are the Rankine, Brayton, and Stirling cycles. Rankine cycle engines are limited to lower temperature ranges (150° to 1100° F) and have lower expected efficiencies (20% to 35%) than other conversion cycles of equivalent engine size (very large units in the 300 MWe to 500 MWe range achieve conversion efficiencies of 42%). However, Rankine cycle power systems are now commercially available, and future cost-performance estimates are fairly certain. Rankine cycle engines may be applied to either large central conversion systems or to small distributed conversion systems. Brayton cycle power systems require high temperature gas technology (1500° F). Efficiencies for Brayton cycles are potentially better than Rankine cycle engines (35% to 45%), but they require more complex, higher temperature collectors and additional engine development. Furthermore, even though large central Brayton cycle engines are possible in solar thermal applications, most development is focused on small engines for distributed conversion systems. Stirling cycle engines offer the best performance potential. Existing engines have achieved 40% experimental efficiency and advanced engines may achieve efficiencies in the 40% to 50% range. It appears that Stirling cycle engines are best suited to distributed systems where their small size and high temperature (1500° F) are better matched. However, the future development of large Stirling engines for central conversion is also a possibility. In both cases, only developmental models and prototypes of solar Stirling engines are in existence today and considerable research and development is required to attain commercial availability. In summary, the trade-off in selecting conversion cycles is one of choosing higher performance, increased complexity, and developmental costs versus lower performance, less complexity and current availability.

B. SYSTEM ALTERNATIVES AND COSTS

As shown in Figure 2-6, there are a large number of different approaches which may be chosen in the design of subsystems and in the final configuration of complete solar thermal power systems. It is the current dilemma of R&D that no particular power system has been proven sufficiently superior to warrant abandonment of all other avenues of study. Consequently, several solar thermal power system concepts are undergoing simultaneous research and development.

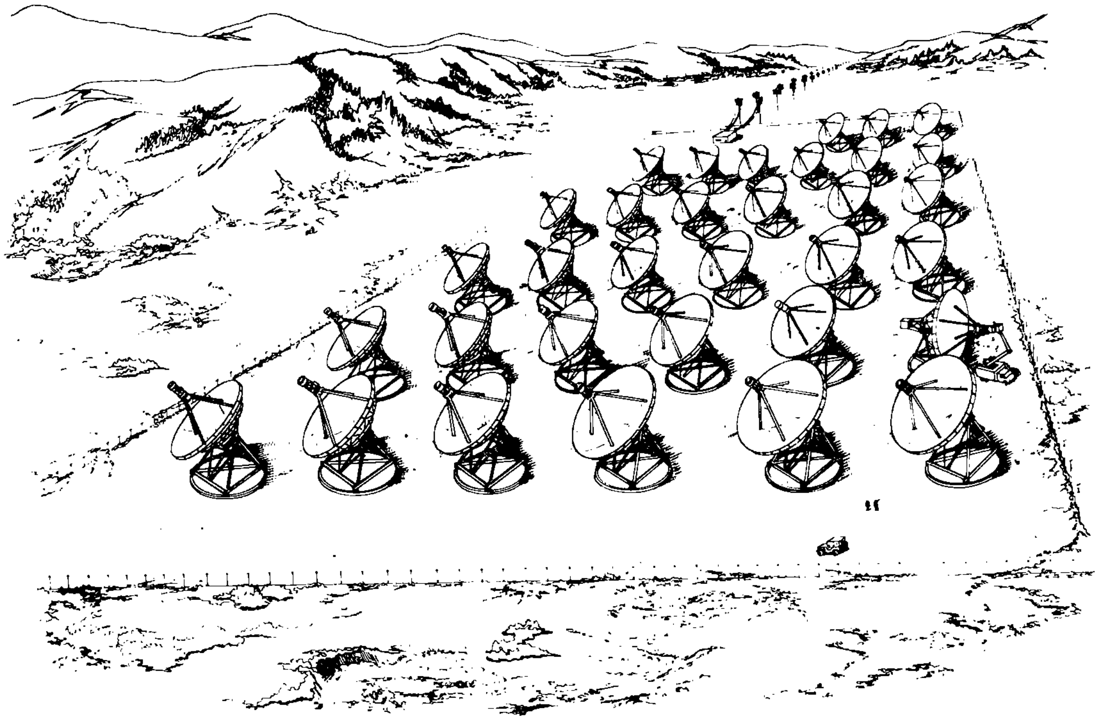


Figure 2-4. Ford Aeronutronic Division, PFDR System with Distributed Stirling Engine Conversion at Focal Point of Each Parabolic Dish

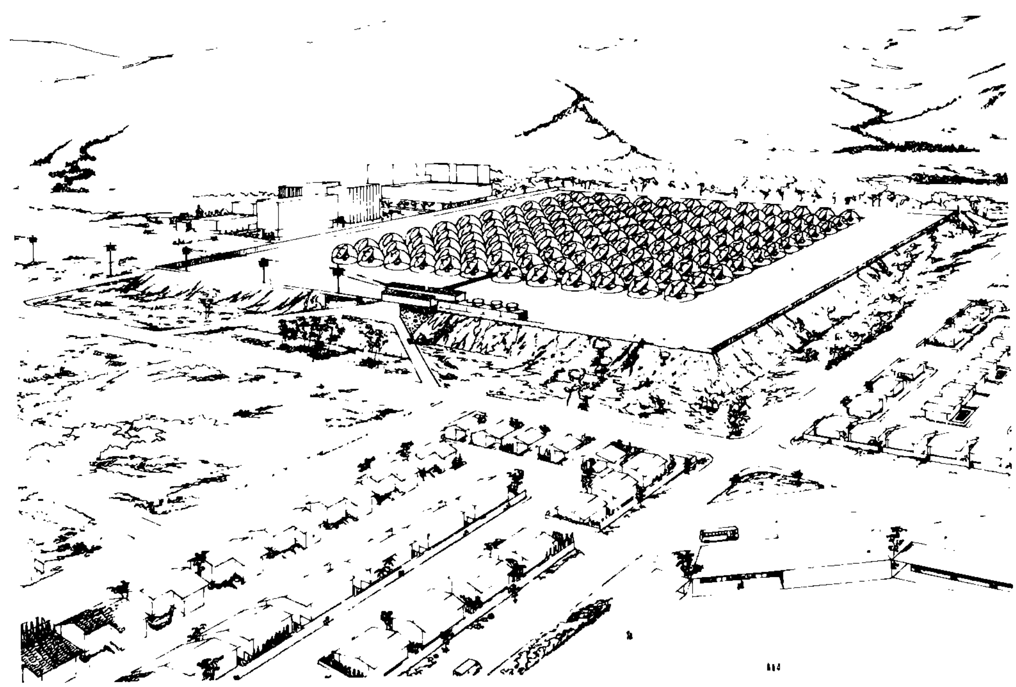


Figure 2-5. General Electric, PFDR System with Steam Transport to Central Rankine Engine Conversion

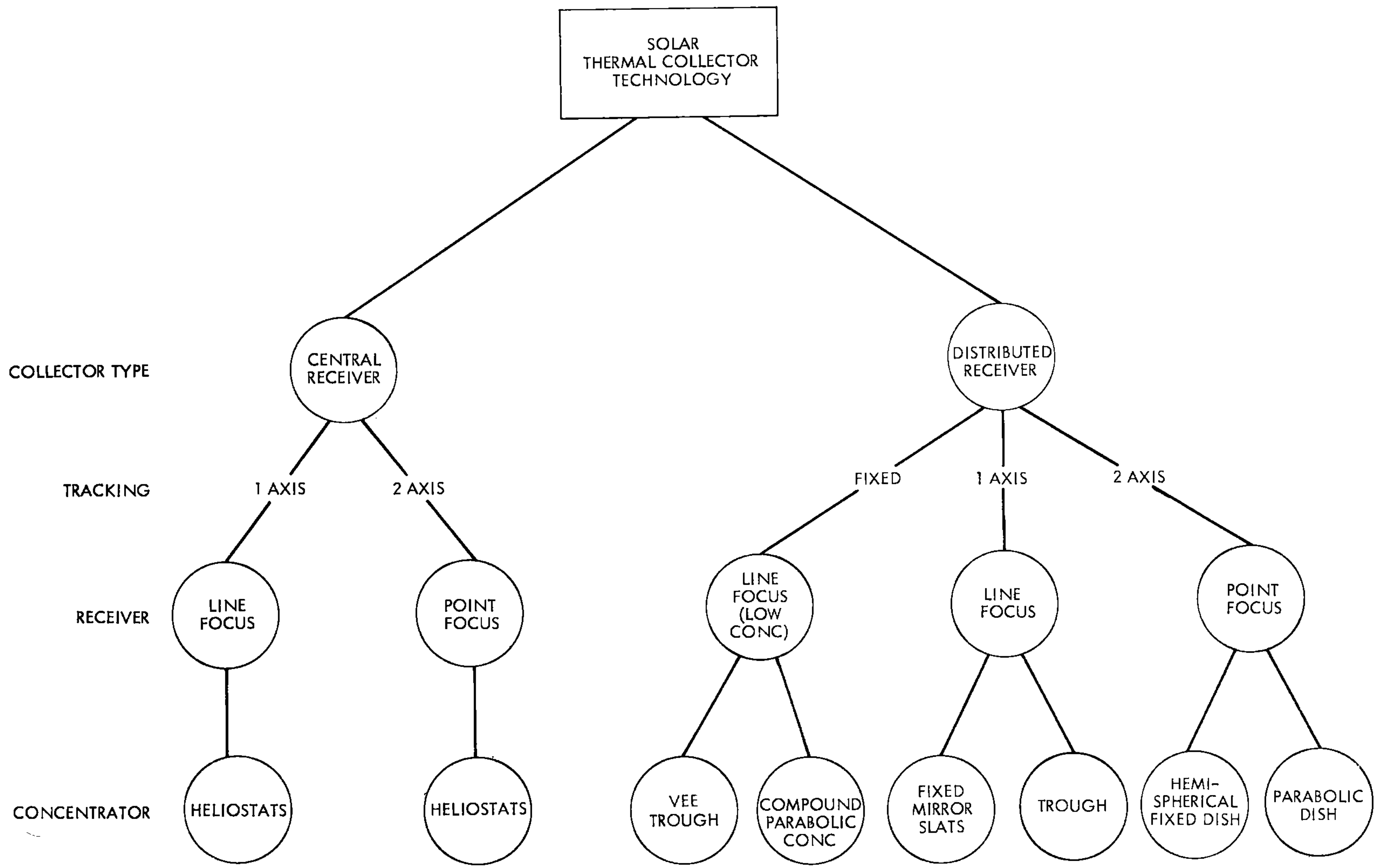


Figure 2-6. Breakdown of Solar Thermal Collector Technology Alternatives Considered in General System Studies (Conversion Cycle Alternatives Not Shown)

The lack of reliable technological forecasts, applications studies, and market studies has delayed the process of selecting the most promising lines of development. However, recent technology comparison studies have indicated that the two-axis tracking or point-focusing systems are superior to one-axis and non-tracking systems for the generation of electricity and industrial process heat.

The solar thermal power system concepts which appear to have the most potential for high temperature energy generation are the point-focusing systems. Three concepts of special interest are the central receiver systems (Figure 2-3), distributed receiver systems with central conversion (Figure 2-2) and distributed receiver systems with distributed conversion (Figure 2-4). These technologies permit the generation of high temperature which in turn greatly improves overall system conversion efficiency. A recent study comparing the capital cost and system efficiency of solar thermal power plants is summarized in Table 2-1.

Several important trade-offs may be made in the development and design of solar thermal power plants. The following four issues are among the most significant.

1. Collector Cost Versus Efficiency

Collectors account for a large proportion of the installed cost of a solar thermal power system. Therefore, collector area and cost will have a significant impact on the overall capital cost of the system. Increased system efficiency directly reduces the required collector area, and less solar insolation is needed to produce the same amount of useful energy. As a result, overall system capital costs are reduced. Current research indicates that high concentration, relatively expensive, two-axis collectors with high efficiency heat engines are justified by present estimates of collector costs and potential conversion efficiencies.

2. Plant Size Effects

A system or subsystem exhibiting economies of scale costs less per unit of energy output as the size of the system is increased. Different size effects are noted in Section II of the working papers, including the impacts of power system size and storage capacity on the relative cost of energy from the solar power plant. For example, it may be cheaper to build a few large systems to take advantage of economies of scale; on the other hand, it may be possible to build many smaller systems or modular systems and reduce overall system capital cost by mass production of the smaller systems or modules. Such a trade-off is not clear at this time and needs further study.

Table 2-1. Comparison of Major System Concepts

Configuration (10 MWe Capacity) (0.4 Capacity factor)				Capital Cost	System Efficiency	Energy Cost	
Collector	Conversion	Transport	Storage	(1977 $/kWe)	(%) (not through storage)	(1977 mills/kWhr)	Note
Central Receiver (heliostat)	Central 600°C Steam Rankine	Thermal heat trans. oils	Sensible heat dual media rock/oil	1320	30	102	2
Central Receiver (heliostat)	Central 820°C Stirling	Thermal liquid metal	Sensible heat liquid metal	1250	40	74	1
Central Receiver (heliostat)	Central 820°C Open Cycle Brayton	Thermal liquid metal	Sensible heat liquid metal	1230	37	79	1
Distributed receiver (dish)	Distributed 1000°C Stirling	Electrical	Redox Battery	1120	45	63	1
Distributed receiver (dish)	Distributed closed cycle Brayton 1100°C	Electrical	Redox Battery	1140	44	75	1
Distributed receiver (dish)	Multi-dish 820°C Stirling	Thermal liquid metal	Sensible heat liquid metal	1000	40	63	1

NOTE: 1) An advanced system which assumes cost reduction by mass production and highly advanced, high efficiency engines for the 1990-2000 year time frame.

2) Baseline system representing near-term technology for reference

SOURCE: Fujita, T., et al, "Techno-Economic Projections for Advanced Dispersed Solar-Thermal Power Plants to Years 1990-2000," DOE/JPL-1060-78/4, November 1978.

3. System Capacity Factor

The capacity factor of a system is defined as energy generated by a system and applied to a load divided by the energy a system could produce if it operated at capacity continuously. In the case of utilities, power systems operated at high load factors are called baseline units; these satisfy the portion of electricity demand that is generally present. Low load factor systems are called peaking units, which are used to supply electricity only when electrical demand exceeds baseline capacity during a peak demand period. Without storage or hybrid firing, most solar systems cannot exceed a 0.3 capacity factor simply because, on average, the sun may shine only eight hours a day. Storage or fossil fuel is needed to provide energy for use when solar insolation is absent and thereby increase the capacity factor of the power system. The trade-off which must be made is between the added cost of energy storage or hybridization versus the value of the energy that is produced. These trade-off questions are very complex and involve the economics of the entire utility system. Ultimately, the configuration of a solar thermal power system will depend significantly on the application requirements of load factor and system reliability. These trade-offs will also require further analysis.

4. Capital and Recurrent Costs

The overall cost of energy generated by a power system is derived from two sources: installed capital cost and recurrent costs such as maintenance, insurance, operation, and fuel. Many trade-offs are present; there are numerous technical and financial trade-offs between the quality and cost of the power plant itself versus the operations, maintenance, and economics of the solar power system. Financial trade-offs are discussed in Volume II, Section IV of this report.

C. COST REDUCTION APPROACHES

There are several technical approaches to cost reduction that are discussed in Section III (Volume II) of the working papers and are briefly summarized in the remainder of this Section.

1. Research and Development

The contribution that R&D can make toward the cost reduction of solar systems involves a combination of selecting optimal technologies and innovative designs. Selecting technologies requires careful estimation of the potential performance, the expected costs, as well as the developmental risks of the many alternative system concepts and subsystems. A difficult choice is then made to invest scarce R&D resources in the development of concepts and subsystem technologies which appear to offer the greatest return in cost reduction. Once a particular concept or technology is chosen, innovative design helps it achieve its potential for performance and cost reduction.

2. Manufacturing

Cost reduction in the manufacturing of solar thermal power systems may be achieved as a result of mass production; when the fixed costs of an investment in factory equipment are spread over a large number of outputs, the per-unit cost of each output is reduced. Close coordination between R&D and manufacturing studies is necessary to capture the full benefit of mass production. As discussed in Section III of this Executive Summary, mass production of many smaller units has a greater cost reduction potential than a few larger units that produce the same overall energy output. The basic question is whether the lower cost of small mass-produced units can outweigh the economies of scale of larger units that result in lower costs for the energy produced.

3. Installation

As improved design begins to lower the capital cost of solar systems, installation will become an increasingly significant cost factor. One way of reducing installation costs is the use of specialized equipment and automated techniques to reduce labor costs. Another method of cost reduction has been suggested by the use of modular systems which are comprised of arrays of individual power producing modules. As modules are installed and made operational, power could be generated and revenues collected during construction; thus lowering the final cost of energy by attaining a faster return on investment. The power plant could be built incrementally to provide additional energy production capacity only as required, with short construction times for each added increment of generating capacity.

4. Operations and Maintenance

Innovative design as well as operations research may play a significant role in reducing the costs of operating and maintaining solar power systems. Increased reliability and safety may reduce unscheduled maintenance and insurance costs and thoughtful design may reduce collector cleaning costs, engine maintenance, the number of operating personnel, and other cost factors. Since these factors are interrelated and involve many uncertainties, research and development efforts should be focused on lowering recurrent costs as well as capital cost, both of which may impact the overall life-cycle cost of solar power systems.

In sum, there are numerous complex trade-offs and critical research and development issues to be addressed. These issues go beyond the traditional scope of government research and development because the ultimate objective is to commercialize alternative solar thermal energy systems as soon as possible. Every aspect of the life-cycle cost of solar energy systems must be analyzed, critical R&D issues identified, cost reduction potential measured, and RD&D (research, development and demonstration) projects initiated to reduce cost wherever possible. Cost reduction through technology forecasting, engineering development, mass production, and refinements in installation, operations and maintenance procedures must be addressed in order to make solar energy competitive with conventional power sources.

SECTION III

ECONOMICS

A. THE TRANSITION TOWARD ENERGY EQUILIBRIUM

Energy demand in the United States will continue to rise, but for a variety of reasons, domestic petroleum and gas supplies will not grow as rapidly. This means that energy prices will increase, and producers may depend more heavily upon foreign reserves. Domestic supplies will be of declining quality, which results in higher costs and environmental side effects. As costs rise, users will begin investing in alternative energy technologies made feasible by these rising prices. One of these alternatives may be dispersed solar thermal power systems. Solar thermal power will have widespread impacts on energy issues; some will be positive, such as reduced dependence on foreign resources, less pressure on fossil fuel prices, greater supply flexibility, and decreased environmental side effects. Nevertheless, questions and uncertainty concerning solar power and the market it faces must be resolved before solar thermal systems become widely used.

One pressing question in solar energy development concerns the potential areas of usage. Four users--industry, remote areas, small communites, and central station utilities--seem to have the greatest potential, as illustrated in Table 3-1. The first two columns list 1978 and 1990 energy use by market sector; the indices are derived by multiplying quantities of each fuel consumed by their respective fuel prices. Column three shows predicted growth in each sector; electricity usage is the major growth area, but almost all fuel uses are expanding. Solar thermal power could affect six of these ten markets; district heating and power systems affect residential and commercial fuel use (the first, fourth and seventh categories), while cogeneration possibilities affect industry usage (the second, third, and eighth categories). How much of an effect solar thermal power has depends on many little-known variables, but the potential impacts in the four user categories are very large.

A number of problems are associated with solar thermal power. The technology is not well developed, thus the initial investment costs will be high. Insolation is intermittent which reduces the operating reliability of solar thermal capacity. Also, solar collectors will require large land areas; high-temperature solar modules placed in residential areas may cause public safety problems. These disadvantages will need to be compared with potential benefits--modularity, flexibility, smaller impacts on environmental quality, fuel savings, and reduced supply uncertainty--in order to evaluate the usefulness of solar thermal energy and the policies aimed at developing it.

Table 3-1. Energy Usage Markets (1978-1990)

	Price x Quantity Index (1978 Dollars x 10^9)		
	1978	1990	Growth, 1978-1990
Residential and Commercial Electricity	51	94	43
Industrial Electricity	20	58	38
Industrial Natural Gas	16	42	26
Residential and Commercial Natural Gas	19	43	24
Coal to Electric Utilities	11	30	19
Petroleum to Electric Utilities	9	23	14
Residential and Commercial Petroleum	16	28	12
Industrial Petroleum	17	26	9
Industrial Coal	3	6	3
Natural Gas to Electric Utilities	5	2	-3

There are many good reasons for developing solar power capabilities; then again, there are many poor ones for subsidizing it. Subsidies should not be given just because the price of other energy sources is rising; higher prices tend to ration scarce resources, to promote conservation, and to motivate a search for substitutes. Additional incentives should be used only when a less than socially desirable amount of solar energy is produced because of market defects; which incentives are used will then depend on the existing market problems.

Thus, it is important to explore the economic issues which solar thermal power systems will encounter. Research efforts should include studies of uncertainty, regulation, demand, and market defects; this will help focus the development of solar power and minimize resource misallocation. It will also reduce the likelihood of implementing subsidies which promote windfall profits rather than economic efficiency.

Market factors include the price of competing technologies, as well as general economic conditions. One of the major competing energy alternatives is grid electricity. Much research still needs to be done on the potential interactions between utilities and solar thermal power, and on the rate structures utilities will be allowed to use. Studies need to be undertaken in the following areas: how utilities choose their rate base; which rate structures (declining block rates, peak-load pricing, etc.) allocate resources most effectively, and which structures are easiest to administer; whether market conditions support the current utility practice of passing increased costs of electricity production on to the consumer; and whether there is some pricing mechanism or metering hardware (such as use of microprocessors) which would allow electricity supply and demand to interact, rather than requiring utilities to have the capacity to meet all demands.

Financial factors and ownership arrangements also change the relative price of solar power to users. Sections III and IV of Volume II noted that subsidies and ownership conditions can have profound effects on the investment decisions users make; more research needs to be done on the magnitude of these effects.

B. FINANCIAL AND OWNERSHIP CONSIDERATIONS

A meaningful evaluation of the potential impact of solar thermal power plants in the energy marketplace of the future must include a detailed study of the costs of such plants relative to the cost of conventional power plants or of other advanced technology power plants such as wind, photovoltaic, Diesels, etc. Although many diverse and subjective factors enter into the decision-making process concerning capital investment in a power generation technology, the element of cost is a critical factor in that process.

Purchasing decisions depend on a number of factors, including alternative energy costs, market expectations, regulations, tax incentives, and ownership arrangements. Section V of Volume II develops a methodology to quantify the life-cycle cost patterns of solar thermal technologies, and compare these costs to available alternatives.

An analysis of the cost of any type of power plant is very complex. It involves more than simply determining the price tag, or first cost, of the plant. It involves looking at the cost not only of buying, but also of operating and maintaining the plant. Consideration must also be given to how these life-cycle costs are affected by the financial context of the owner(s) of the plant. A variety of ownership alternatives are possible: private utilities, public utilities, industrial companies, commercial companies, cogeneration joint ventures between utilities and industry, third party owners (who lease plant equipment), etc. The operational mode of a power system and the applicable financing opportunities, requirements, and incentives will differ for each of these ownership alternatives, causing the life-cycle costs to vary correspondingly. Finally, the cost of a plant varies with the design, the construction time, and with the distribution of costs over the construction period.

In order to determine how all of these factors define, in a standardized manner, the cost of investment in various power technologies to a variety of owners, a model is required which has the flexibility to accurately represent the appropriate financial context for a variety of ownership alternatives. In addition, it must provide financial statements consistent with accepted business accounting practices and financial systems.

The Solar Thermal Economic Analysis Methodology (STEAM) is based on the principles of life-cycle analysis discussed in detail in Section V of Volume II. It requires the calculation of the cash flows associated with an investment for each year in the investment project time horizon. A primary purpose of the model is to enable the user to determine the quantitative effects of variations in the design, ownership, construction, operation, financing and taxation of a variety of small power systems. This type of information is very valuable in evaluating the potential effects of national and state legislation, regulations and policy on the economic viability of small solar power systems in a variety of potential markets.

C. MARKET PENETRATION

Even if solar thermal technologies are well designed and have costs similar to alternatives, these do not guarantee that solar thermal systems will acquire a significant share of energy demand. Demand share depends on many other factors; Section XII (Volume III) identifies three of these factors: the prices of alternatives, financial arrangements, and management problems.

Management of solar thermal technologies can be important; poor timing when introducing a new power system can decrease the system's market acceptance. To counter this problem of mistiming, many firms rely on market penetration analysis to forecast production needs.

Market penetration modeling is the principal component in the market analysis of dispersed solar thermal energy technologies. The solar energy market penetration models are used to project the demand for a particular solar energy technology in a given market. Alternative solar technologies may thus be evaluated and compared in order to concentrate current, limited RD&D funds in those designs which appear to be the most viable. Because of the pivotal role of market penetration modeling in determining the development of dispersed solar thermal energy technologies, it is important to understand the analysis used in market penetration modeling as well as its limitations.

Section VI (Volume II) pointed out that these penetration models cannot forecast very well; market penetration estimates depend strongly upon the assumptions made, and these assumptions have not tended to be particularly valid. Simply because an analysis has a quantitative foundation does not guarantee the data which are generated are meaningful. Valid data can be entered in a spurious model to yield meaningless numbers. This appears to be the case with solar energy market penetration analysis. Thus, there is an immediate need for better forecasting tools; some of these market forecasts might be based on current econometric models and an analysis of buyer behavior. It would then be easier to develop solar thermal systems which would meet demands in an optimal manner.

SECTION IV

SOLAR RESOURCES

Many of the factors influencing the market potential of solar power vary in their spatial distribution. If the use of solar thermal capability will first occur in areas where regional variations favor solar energy, then there is a need to identify these factors.

One of the most important factors is the variability of the solar resource itself. As Section VII (Volume II) emphasizes, insolation varies with the season, local weather conditions, latitude, degree of urbanization, presence of pollutants, and land use factors. There is an immediate need for better understanding of these insolation changes. Section VII recommends that basic research be undertaken to improve understanding of seasonal and daily variations in solar availability, so that solar thermal systems may be located more efficiently. The data gaps in the insolation measurement network should be filled by upgrading individual stations or expanding the coverage of the network. Research should also include a study of variations in urban and rural insolation, an identification of pollution sources and their persistence in the atmosphere, and a study of weather variations across climatic types. This research will result in more reliable insolation data and a better basis from which to make system siting decisions.

Section VII examines the basic problems associated with insolation assessments and suggests improvements. The first part focuses on the nature of insolation variation on the earth's surface as a result of earth-sun geometry. Once these predictable variations are described, the more difficult complications introduced by atmospheric and terrestrial factors are presented. Foremost among these factors is variation in cloud cover (occurrence and persistence) in different parts of the country. Other factors are also noted (e.g., dust and aerosols). Variability of weather patterns is suggested as an important force in the eventual acceptance and success of a solar thermal system. To optimize the operation of any solar conversion system requires a clear understanding of the insolation resource and reasons for its variation, whether geometrically or terrestrially induced.

A brief description of the fundamental methods by which solar energy is collected and a basic assessment of their suitability in different geographic locations is also included in Section VII (see Figures 4-1 and 4-2). The most applicable insolation models and the current insolation data bank are evaluated. The paucity of insolation data introduces a degree of uncertainty in the site selection process, which may significantly influence the success of a particular technological option. Although many techniques are available for prediction of insolation, none is perfect.

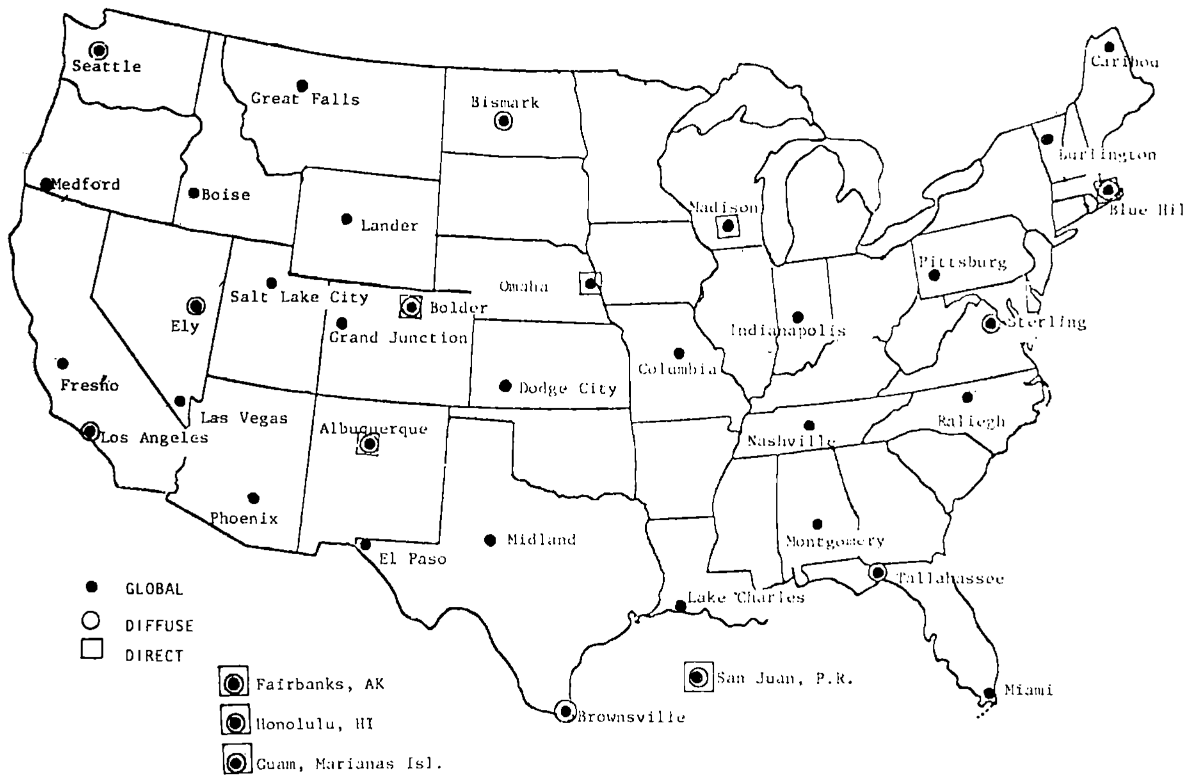


Figure 4-1. Existing Solar Monitoring Network
Source: Air Resources Laboratory

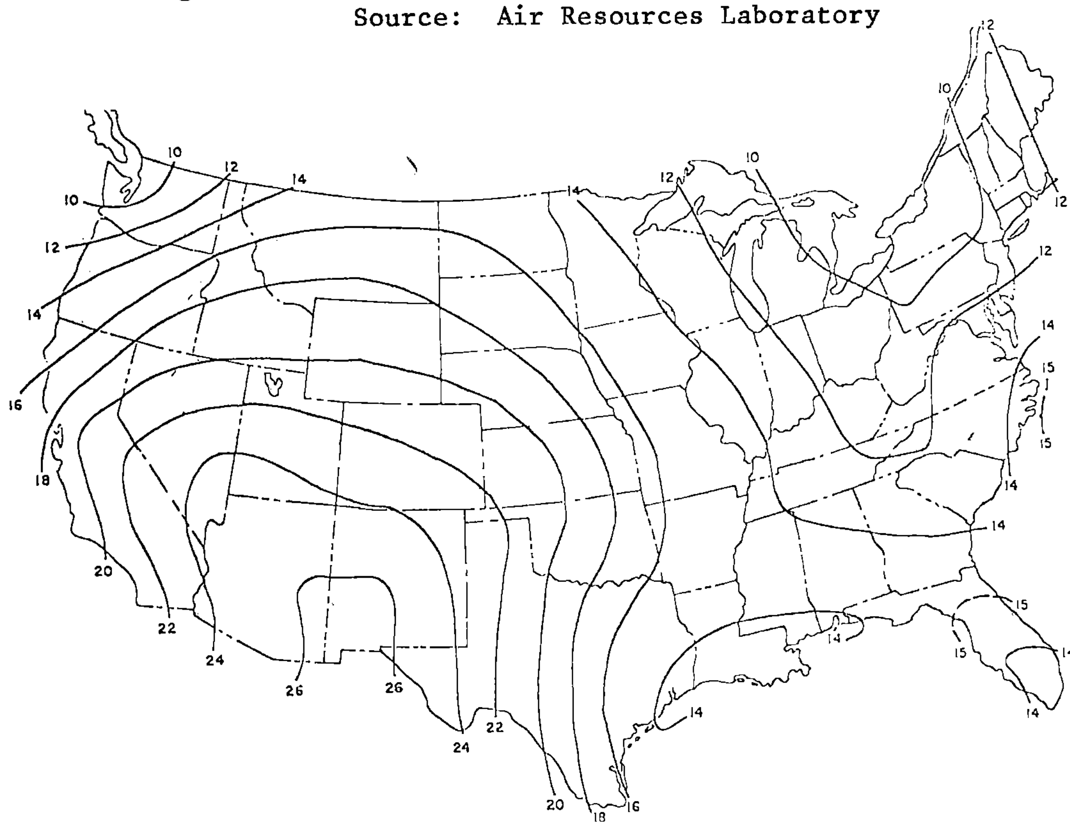


Figure 4-2. Annual Direct Insolation (measured in megajoules/m^2)
Source: U.S. Department of Energy

The last part of Section VII suggests methods by which the assessment of insolation can be enhanced. Essentially these methods focus on development of a finer regionalization of the country. This can be accomplished by the evaluation of insolation data. One method of evaluation is to analyze the variation in weather types in the different climatic regions. For example, arid regions, are often considered to be the first targets of commercialization, yet have some of the greatest weather variabilities of any climatic type. An assessment of cloud cover and other weather factors should provide valuable information to individuals involved in the identification of candidate sites. Other regionalization techniques, including instrumentation, are suggested to enhance the existing insolation assessments and improve the likelihood of successful market penetration.

Furthermore, the data attained by the above techniques might be analyzed through map overlay analysis. Problems inherent in manual techniques of dealing with multiple spatial data sets (i.e., maps) are examined, and the two primary techniques of performing an automated overlay analysis are compared in the working paper. Existing software for handling spatial data (developed at JPL for the space program) is available, and a study approach can be developed for using this system for the identification of candidate areas for early market penetration efforts.

Other local factors affect the competitive potential of solar thermal power within each region. These include variations in: fossil fuel distribution, labor costs, employment patterns, electricity rate structures, delivery costs, population concentrations, demand load profiles, environmental side effects, and land use requirements. Each of these factors affects the competitiveness of solar thermal power. There is a need to list all of these critical factors, to obtain reliable and consistent data on them, and to portray the geography of each factor. In this manner, it will be possible to identify those areas with the greatest potential as users of solar thermal power, and to determine which regions and sectors will be subject to the greatest impacts of solar thermal technology.

SECTION V

FEDERAL ROLE IN ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION

If there are additional social benefits to solar thermal usage which are not reflected in the private market for energy, then there may be some justification for government involvement in solar power development. Thus, one of the first areas of research necessary for better federal interaction with the market process is an analysis of which stages of solar thermal development are best handled by the private commercial process, and for which areas economic forces alone do not yield an optimal solution.

Having identified areas where government involvement is appropriate, federal agencies can begin to carefully define the issues which exist and the policy tools to mitigate problems within each area. Studies should attempt to estimate the extent of market imperfections, and the policies or incentives which would overcome these imperfections with the least disruption of economic activities. Thus, there is a need to measure how the impacts of incentives vary with the form of solar thermal ownership, and how each incentive affects user costs and investment.

Much thought must go into the criteria government agencies use for decision making purposes. For example, what criteria will be used in siting decisions, or in deciding insolation rights? Will rate structure decisions be based on average or marginal costs? On what alternative fuel-use scenarios will solar energy choices be based? These questions must be carefully considered to avoid arbitrary decisions.

Finally, some inquiry should be made into the problems government regulation and intervention cause in the marketplace. Sections X and XI (Volume III) observe that private manufacturers are reluctant to invest in solar energy because of government patent policies, competition from federal R&D, institutional biases against small firms, lack of emphasis on market conditions, and limited involvement of potential users in federal innovation efforts. If government involvement in these areas is to continue, it will be more effective if it develops better manufacturing support and communication. Studies should also attempt to measure the costs energy regulations impose on society, and to determine whether these regulations are worth the cost. Two examples of regulatory problems which solar thermal power may face are the questions involved in cogeneration rules and hybridization issues. First, will the ownership of solar cogeneration facilities with buy back agreements (utilities must purchase surplus solar generation at a given price) subject solar power owners to the same regulations as utilities? Secondly, hybrids (solar power systems with fossil fuel back-up) may be the most efficient use of energy resources; how costly are regulations which forbid the construction of new power plants using natural gas as a back-up fuel? These are two examples where regulation could lead to a less than optimal solution. This indicates that federal involvement should be reviewed in light of the problems it may create.

SECTION VI

CONCLUSIONS

Many complex issues remain in the development of solar thermal power; these issues must be resolved before solar power becomes a widely used energy alternative. This summary has suggested some of the more pressing research needs; investigations of these problems will greatly assist the technological and commercial viability of solar thermal energy.

Perhaps specific suggestions are of less importance than the principle that a realistic appraisal of the technological, economic, social and environmental problems is required before real progress can be made toward the development and application of solar thermal technology. The programmatic guidelines that are identified should be of interest to the public, Congress, and all other decision makers who affect the conduct of the nation's solar energy programs as well as those responsible for its implementation. A common understanding and awareness of the difficulty and complexity of solar energy innovation may create a healthier climate for technological progress. It is believed that wise energy policy decisions are more likely in an atmosphere where major uncertainties are expressly defined, realistically appraised, and systematically addressed.