A BIBLIOGRAPHY OF KEY REPORTS PERTAINING TO THE ECONOMIC AND TECHNICAL ASSESSMENT OF SOLAR THERMAL POWER SYSTEMS

OCTOBER 1983

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Prepared for the SPSS Working Group for
Economic Assessment of Solar Power Systems
of the International Energy Agency (IEA)

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1.0 INTRODUCTION

The following bibliography of reports dealing with various aspects of the technical and economic assessment of solar thermal technologies was assembled at the request of the SPSS Working Group for Economic Assessment of Solar Power Systems of the International Energy Agency (IEA). Selection of the reports published by the United States Department of Energy was performed in cooperation with Dr. J. Woodard, Technical Program Integrator for the Solar Thermal Program, and staff from Sandia Laboratories, Livermore, California.

Abstracts for European reports were obtained from copies provided to the author by members of the Working Group and do not necessarily represent all the pertinent works available.

Translations from the German were provided by Mr. G. Gross and Dr. H. Neidlinger of SERI.

2.0 UNITED STATES DEPARTMENT OF ENERGY SOURCES

2.1 Design, Cost and Performance Comparisons of Several Solar Thermal Systems for Process Heat, SAND 79-8279, Vols. I-V, P. J. Eicher, et al, Sandia National Laboratories, March 1981.

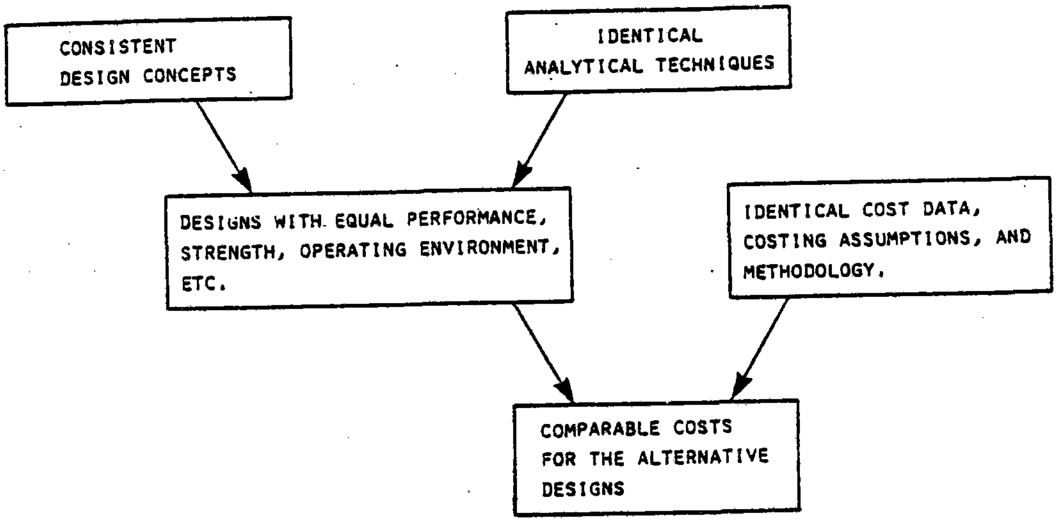
Conceptual designs of central receiver, parabolic dish, and parabolic trough systems are presented for several process heat applications. Cost and performance estimates are made for each of these designs and these are used to calculate levelized delivered process heat costs. The results indicate that central receiver systems will provide energy costs competitive with that afforded by the parabolic trough and parabolic dish systems over the range of demand sizes and temperatures studied--above 3 MW_t and above 93°C (200°F).

The application of solar thermal technologies to production of heat for agricultural and industrial processes has received increased attention in the Department of Energy's solar program during the last several years. Because of the relative newness of this interest, no analysis to date has compared the potential cost and performance (in other words the energy cost) of the various solar thermal technologies as producers of process heat. There have been a number of comparisons of solar thermal technologies in electric power production, but, for several reasons, there is no assurance that rankings which are obtained from those studies will apply to thermal applications. The main purpose of the study described here was to make an initial cost and performance comparison of a number of the potential technologies which could be used for production of process heat.

A large number of solar thermal technologies could be compared for these applications--ranging from stationary flat plate collectors to the two axis tracking systems such as central receiver and parabolic dishes. The authors chose to focus on three--central receiver, parabolic dish, and parabolic trough systems. The reasons for this selection were the fundamental design similarities of these technologies and the wealth of written and verbal information which is available.

The diversity of process heat applications is also large, but two key characteristics are the quantity and temperature of the energy required. It is expected that the relative cost and performance of solar process heat systems might depend on each of these parameters. Power requirements ranging from heating for single family dwellings (approximately 10^5 BTU per hour or equivalently 2.9 x 10^{-2} MW) to the thousands of megawatts required by steel producers could be considered. Temperatures range from close to ambient to over 1093°C (2000°F). Four different demand sizes--3, 30, 300, and 1500 MW--were chosen for study and four temperatures were chosen--93°C (200°F), 149°C (300°F), 316°C (600°F), and 1093°C (2000°F). This range of sizes and temperatures was chosen to determine where "optimum" applications for each of the technologies might lie.

The goal of this study was to develop comparable cost and performance estimates for each of the technologies. To ensure that these cost estimates were comparable, it was necessary to develop designs from the "bottom up" for each of the systems. The meaning of comparable designs is illustrated below. Systems must be designed to the same standards of reliability, survivability, etc., using the same methods of analysis. The performance of the systems must then be estimated using equivalent techniques. Similarly, system cost must be built up from the piece-part and component level using the same cost data base.



Methodology for Comparable Design and Cost

There are pitfalls in the insistence on comparability. Carried to its extreme, one could end up with components which are inappropriate and inordinately expensive for a particular technology. The method of avoiding these pitfalls was to obtain the documentation of designs for each of the technologies. Study of this documentation was then followed by visits with various designers of each of the technologies. Via this process the attempt was made to ensure that, while designs were comparable, they were not so radically different from designs being considered for each of the technologies as to be unacceptable.

A study such as this is an iterative process. It begins with an initial set of ground rules, assumptions and parameter values which are derived in part to obtain comparability. However, as the study progresses, it becomes clear that one or more of the parameter choices has an inordinate impact--negative or positive--on one of the technologies. It is then necessary to determine the magnitude of the impact and whether it is desirable to change the offending parameter value. This could be an almost infinite process but it must be terminated at some reasonable point. This decision to terminate the process in turn limits the range and strength of conclusions which can be reached because one or more of the technologies may not be fully optimized. As will be seen in the section summarizing this study, the authors are unwilling to categorically state that the central receiver is a better cost/performer than troughs or dishes even though the distributed systems are estimated to have significantly higher energy costs. The volumes which make up this report all indicate areas for each of the technologies where there is the potential for further optimization but which there was not time to fully explore in this work.

The bulk of the analysis in this study was carried out on those components which are greatly different among the three systems--concentrators, receivers, and piping systems. Detailed information on the design, cost and performance of these subsystems and on the overall systems is contained in Volumes II-V of this report. Heat exchangers coupling the solar collection systems to the processes were assumed to have the same cost and performance for each of the technologies. The details of the processes using the energy were not considered to be important to the comparison; the process was simply a demand for a certain amount of thermal power at a certain temperature. Finally, storage was not considered in this study since the same storage technology could probably be used by each of the technologies and, in any case, would not greatly affect the relative cost/performance.

2.2 Final Report: A Comparative Ranking of 0.1-10 MW_e Solar Thermal Electric Power Systems, SERI/TR-351-461, 2 Volumes, J.-P. Thornton, et al, Solar Energy Research Institute, August 1980.

The Division of Solar Thermal Energy Systems, Office of Solar Industrial Applications of the U.S. Department of Energy (DOE) initiated the Small Solar Thermal Power System Program to explore the technical, economic, and institutional feasibility of providing remote load centers, small communities, rural areas, and industrial users with supplementary energy sources. The objective of the Small Solar Thermal Power System Program was to establish the technical readiness of cost-competitive solar thermal power systems. A Small Communities Application project supported the program. The U.S. Department of Energy deleted responsibility for both technical management of the small communities project and for development of experimental systems that achieve the objectives of the program to the Jet Propulsion Laboratory in Pasadena, California.

Delegated

To identify the most likely options for long-term commercialization of small solar thermal electric power systems, DOE requested a comparative analysis of the major generic solar thermal electric systems. The Small Solar Thermal Electric Power Systems Study (SPSS) began in April 1978 at both the Solar Energy Research Institute (SERI) and Battelle Pacific Northwest Laboratories. This report describes the results of the work at SERI.

The original objective of the study was to project the mid-1990 cost and performance of selected generic solar thermal electric power systems for utility applications and to rank these systems by criteria that reflected their future commercial acceptance. This study considered plants with rated capacities of 1 MW_e to 10 MW_e, operating over a range of capacity factors from the no-storage case to 0.7 and above. Later, the study was extended to include systems with capacities from 0.1 MW_e to 1 MW_e, a range that is attractive to industrial and other nonutility applications.

In the first phase of SPSS, completed in October 1978, generic systems and their variations and a simulation technique for projecting future cost and performance were selected, ground rules were established, and a ranking method was defined. Eleven systems from 1-10 MW_e rated capacity were examined during the second phase of SPSS, completed in May 1979. The third and last phase of SPSS, completed in September 1979, evaluated systems with rated capacities of 0.1-1 MW_e. Because utilities usually are not interested in systems of this capacity range, ground rules were modified and ten systems were modeled for industrial or small community use with an available backup power source such as a grid or diesel generator. Unlike the 1-10 MW_e systems, these smaller systems were not considered to operate as an integral part of the grid.

System performance was based upon environmental data taken at a site near Barstow, California. This site was chosen because of its desirability for a solar power plant and because insolation data was available in sufficiently small time increments (15 minutes) to allow detailed simulation of plant performance. The insolation values used in the performance code were obtained from the 1976 Barstow environmental data tape supplied by JPL.

The ranking or selection of solar thermal technologies for power applications were done with the active participation of representative decision makers of the various user markets. Small solar thermal electric power systems may be applied in small communities, electric utilities of many sizes, isolated facilities, military bases, industry, and agriculture, and many rural and undeveloped areas. In addition, influential nonusers with significant interests such as Federal and State agencies, researchers, engineers, and public interest groups will affect the development of these systems. SERI incorporated the opinions of four groups of decision makers in the ranking: (1) the electric utility industry and its auxiliary consultants and regulators, (2) the industrial user community, (3) other potential user groups, and (4) the research and development community, both technical and nontechnical.

The cost estimates for each technology and the resulting energy costs do not necessarily represent either established DOE goals or the ultimate potential costs of a system. Emphasis has been placed upon using costs that can reasonably be achieved by the mid-1990's, as well as upon using a common economic scenario so that a credible ranking could be obtained.

The results of this study are relevant only to plants used for electrical power generation in the 0.1-10 MW_e capacity ranges and are not necessarily transferable to applications such as industrial process heat (IPH) or cogeneration.

Volume I of this report summarizes the results for both the 1-10 MW_e and 0.1-1 MW_e capacity studies. The second volume contains tabularized system performance summaries, ranking methodology data, and a complete set of key references. Both volumes are available from the National Technical Information Service.

2.3 Assessment of Solar Options for Small Power Systems Applications, PNL 4000, 5 Volumes, W. W. Laity, et al, Battelle Pacific Northwest Laboratories, September 1979.

Under the sponsorship of the U.S. Department of Energy's Division of Central Solar Technology, the Pacific Northwest Laboratory performed a comparative analysis of solar thermal conversion concepts that are potentially suitable for development as small electric power systems (1 to 10 MW_e). Cogeneration and total electric systems were beyond the scope of this study.

Seven generic types of collectors, together with associated subsystems for electric power generation, were considered. The collectors can be classified into three categories: 1) two-axis tracking (with compound-curvature reflecting surfaces), 2) one-axis tracking (with single-curvature reflecting surfaces), and 3) nontracking (with low-concentration reflecting surfaces). All seven collectors were analyzed in conceptual system configurations with Rankine-cycle engines. In addition, two of the collectors (the Point Focus Central Receiver and the Point Focus Distributed Receiver) were analyzed with Brayton-cycle engines, and the latter of the two also was analyzed with Stirling-cycle engines. With these engine options, 10 systems were formulated for analysis.

Conceptual designs developed for the 10 systems were based on common assumptions of available technology in the 1990 to 2000 time frame. No attempt was made to perform a detailed optimization of each conceptual design. Rather, designs best suited for a comparative evaluation of the concepts were formulated. Costs were estimated on the basis of identical assumptions, ground rules, methodologies, and unit costs of materials and labor applied uniformly to all of the concepts.

The computer code SOLSTEP was used to analyze the thermodynamic performance characteristics and energy costs of the 10 concepts. Year-long simulations were performed using meteorological and insolation data for Barstow, California, as input to the code. Results for each concept include levelized energy costs and capacity factors for various combinations of storage capacity and collector field size.

For all 10 concepts, subjective values were estimated for four additional power plant characteristics: plant flexibility, forced outage rate, environmental and safety effects, and R&D necessary for commercialization.

Multiattribute utility methodology was used to rank the 10 concepts. To quantitatively establish the importance to decision makers of each plant characteristic (attribute) used in the ranking, 37 interviews were conducted with personnel from the Electric Power Research Institute, Edison Electric Institute, and nine utilities in the Southeast and Southwest. Value indexes for the 10 concepts were calculated and used to rank the concepts and to determine concept groupings with statistically significant differences.

Results of this study led to the following conclusions:

- When only the three more traditionally compared attributes of levelized energy cost, capacity factor, and fixed costs were considered, concepts using central receiver subsystems ranked above those with distributed receivers; concepts with thermal storage ranked above those with electric storage at higher capacity factors (>0.4); and two-axis tracking concepts ranked above one-axis tracking concepts which, in turn, ranked above the nontracking concept.

- When all seven attributes were used for ranking, the central receiver concepts dropped to a significantly lower group, primarily because of higher forced outage rate. In addition, the central receiver Brayton concept was penalized for higher R&D costs. Distributed line focus and nontracking concepts moved up in ranking, particularly at high capacity factors, due primarily to relatively low R&D costs.

- Utility decision makers indicated that plant flexibility, forced outage rate, environmental and safety effects, and R&D requirements significantly affect the commercialization potential of solar concepts.

- The Point Focus Central Receiver with Rankine power conversion and the Point Focus Distributed Receiver with Brayton or Stirling power conversion consistently ranked high.

- The Line Focus Distributed Receiver with a tracking receiver and the Line Focus Central Receiver consistently ranked low.

2.4 Assessment of Generic Solar Thermal Systems for Large Power Applications, PNL 3533, 2 Volumes, W. J. Apley, et al, Battelle Pacific Northwest Laboratory, November 1980.

Under the sponsorship of the U.S. Department of Energy's Division of Solar Thermal Energy Systems, the Pacific Northwest Laboratory performed a comparative analysis of solar thermal conversion concepts that are potentially suitable for development as large electric power systems (50 to 200 MW_e). Cogeneration and solar/fossil hybrid systems were beyond the scope of this study.

Seven generic types of collectors, together with associated subsystems for electric power generation, were considered. The collectors can be classified into three categories: 1) two-axis tracking (with compound-curvature reflecting surfaces), 2) one-axis tracking (with single-curvature reflecting surfaces), and 3) nontracking (with low-concentration reflecting surfaces). All seven collectors were analyzed in conceptual system configurations with Rankine-cycle engines. In addition, two of the collectors were analyzed with Brayton-cycle engines, and one was analyzed with a Stirling-cycle engine. With these engine options, and the consideration of both thermal and electrical storage for the Brayton-cycle central receiver, 11 systems were formulated for analysis.

Conceptual designs developed for the 11 systems were based on common assumptions of available technology in the 1990 to 2000 time frame. No attempt was made to perform a detailed optimization of each conceptual design. Rather, designs best suited for a comparative evaluation of the concepts were formulated. Costs were estimated on the basis of identical assumptions, ground rules, methodologies, and unit costs of materials and labor applied uniformly to all of the concepts.

The computer code SOLSTEP was used to analyze the thermodynamic performance characteristics and energy costs of the 11 concepts. Year-long simulations were performed using meteorological and insolation data for Barstow, California. Results for each concept include levelized energy costs and capacity factors for various combinations of storage capacity and collector field size.

Multiattribute utility methodology was used to rank the 11 concepts. The levelized energy cost (LEC) and capacity factor (CF) were calculated using SOLSTEP. The other plant characteristic (attribute) used in the ranking process, forced outage rate (FO), was determined individually for each of the concepts. To quantitatively establish the importance to decision makers of each attribute used in the ranking, 48 interviews were conducted with personnel from the Electric Power Research Institute and 24 utilities in the West and Southwest. Value indexes for the 11 concepts were calculated and used to rank the concepts and to determine statistically significant differences between concepts.

When conclusions were made based on a comparison of levelized energy cost only,

- at low capacity factors in which no storage is employed, four concepts (PFCR/R, PFCR/B, PFDR/B, and PFDR/S) had significantly lower costs while two concepts (LFDR-TR and LFCR) had significantly higher costs. The LCNT concept yielded prohibitively high energy costs.

- At higher capacity factors (0.4 to 0.7), one concept (PFCR/R) had a significantly lower cost while six concepts (LFDR-TR, PFCR/B-EES, LFCR, PFDR/S, LFDR-TC, and PFDR/B) had significantly higher costs. The LCNT concept again yielded prohibitively higher energy costs.

- At the lowest energy cost for each concept, regardless of capacity factor, one concept (PFCR/R) had a significantly lower cost, three concepts (LFDR-TR, LFDR-TC, and LFCR) had significantly higher costs, and one concept (LCNT) has a prohibitively higher energy cost.

When the 11 concepts were ranked on all three attributes (LEC, CF, FO) used together,

- for all power levels, the PFCR/R was ranked highest at optimal, minimum LEC, and 0.7 capacity factors. The FMDF and PFDR/R shared second and third places at these capacity factors. There was, however, no statistically significant difference among the PFCR/R, FMDF/R, and PFDR/R at these capacity factors.

- For all power levels, the LCNT was ranked lowest due to its extremely high levelized energy cost.

- For all power levels where no storage was available, the PFDR/S was ranked highest, with the PFDR/B ranked second highest.

Based on the findings of this study, four recommendations are offered:

1. The Point Focus Central Receiver/Rankine concept with molten salt as the transport and storage fluid should receive highest priority for commercial development as a large electric power plant.

2. The line focus systems (distributed and central receiver) should receive reduced priority for development as large electric power plants.

3. The LCNT should not be developed as a large electric power plant.

4. Predictions of performance for solar thermal concepts should be reported on the basis of a standard day, standard site (for example, Middletown, U.S.A.). Energy cost estimates should be based on annual performance.

2.5 A Description and Assessment of Large Solar Power Systems Technology, SAND 79-8015, L. N. Tallerico, Sandia National Laboratory, August 1979.

This document summarizes the systems being developed by the Department of Energy's Large Solar Thermal Central Power System Program. Included are the technical concepts upon which the systems are based and, to the extent possible, estimated cost, performance, and assessment of typical systems. The intent is to provide potential users with an overview of present technologies and those technologies that will be available within the next few years.

Sandia Laboratories' assessments of the strengths and weaknesses of each technology have been included in the hope that developers of the technology will be able to improve component and system designs to the point where they become fully competitive with alternate energy sources. This document will be revised periodically (possibly at 1-2 year intervals) to incorporate new developments.

Further information on the particular designs may be obtained from the reports presented in the bibliography.

The cost of these systems is important to prospective users. This report contains cost estimates by commercial contractors and Sandia Laboratories. In many cases, these cost projections may differ because of differences in assumptions, degree of optimism, or approach. In all cases, the authors tried to specify who made the estimates. No claim is made that contractor estimates are more or less accurate than the Sandia estimates. However, Sandia has attempted to normalize out the differences which are not attributable to fundamental technological differences.

The options expressed in this document are based on the best available information and on independent analysis. However, since new technology is being developed rapidly, conclusions presented in this document may not hold in the future. Therefore, potential users of these technologies are urged to make their own assessment of alternatives and draw their own conclusions.

2.6 <u>Solar Power Tower Design Guide: Solar Thermal Central Receiver Power Systems, a Source of Electricity and/or Process Heat</u>, SAND 81-8005, K. W. Battleson, Sandia National Laboratories, April 1981.

The technology of solar-powered energy systems using the central receiver concept (referred to as the "power tower" in the popular press) is rapidly approaching readiness for electric utility and industrial process heat application. A 10 MW_e pilot plant is now in operation near Barstow, California. This technology promises to become a cost competitive energy alternative, even to coal.

This document provides the information necessary to perform preliminary evaluations of whether a solar thermal central receiver plant is technically and economically feasible, as well as desirable, for the potential user's application. The cost elements, performance, and operation of solar central receiver systems are described.

The scope of the document is limited to solar central receiver plants. It discusses actual component hardware as well as plant conceptual designs. Advanced concepts for which little or no testing has been conducted are not discussed. The end use application of the solar-derived energy, industrial process heat or electricity production, is not treated in depth.

2.7 Characteristics of Current Solar Central Receiver Projects - October 1982, SAND 83-8013, A. F. Baker and A. C. Skinrood, Sandia National Laboratories, May 1983.

The information contained in this report was summarized from responses to a questionnaire sent to representatives of six international solar central receiver projects: Eurelios (Italy), CESA-1 (Spain), International Energy Agency Small Solar Power Systems (Spain), Sunshine (Japan), Themis (France), and Solar One (U.S.). The questionnaire was developed for use at the International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects held in Claremont, California, from October 19 to October 22, 1982. Comments on the questionnaire should be directed to the authors; questions pertaining to a specific project should be addressed to that project.

2.8 An Investigation of Learning and Experience Curves, SERI/TR-353-459, F. Krawiec, J. Thornton, and M. Edesses, Solar Energy Research Institute, April 1980.

This study assesses the applicability of learning and experience curves for predicting future costs of solar technologies, and the major test case is the production economics of heliostats. Alternative methods for estimating cost reductions in systems manufacture are discussed, and procedures for using learning and experience curves to predict costs are outlined. Because adequate production data often do not exist, production histories of analogous products/processes are analyzed and learning and aggregated cost curves for these surrogates estimated. If the surrogate learning curves apply, they can be used to estimate solar technology costs. The steps involved in generating these cost estimates are given. Second-generation glass-steel and inflated-bubble heliostat design concepts, developed by MDAC and GE, respectively, are described; a costing scenario for 25,000 units/yr is detailed; surrogates for cost analysis are chosen; learning and aggregate cost curves are estimated; and aggregate cost curves for the GE and MDAC designs are estimated. However, an approach that combines a neoclassical production function with a learning-by-doing hypothesis is needed to yield a cost relation compatible with the historical learning curve and the traditional cost function of economic theory.

2.9 <u>Research and Development Project Evaluation and Selection Methods for the Solar Thermal Technology Program</u>, SERI/TR-251-1573, F. Krawiec, Solar Energy Research Institute, February 1983.

This study discusses the ranking of R&D options for long-term, high-payoff research and development in the Solar Thermal Technology Program considering the four general classes of ranking methods: economic, decision theory, constrained optimization, and scoring. The scoring method is proposed as the most suitable ranking technique to develop a balanced portfolio of R&D program elements. Procedure for implementation of the scoring method for Solar Thermal Technology Program activities evaluation and selection is outlined. Practical applicability of the scoring method to evaluate and select the Solar Thermal Research Program activities is demonstrated. The major conclusion is that the scoring method augmented with the subjective probabilistic risk assessment procedure, is a suitable ranking technique to develop a balanced portfolio of R&D program elements.

2.10 International Workshop on the Design, Construction and Operation of Solar Central Receiver Projects, SAND 82-8048, Sandia National Laboratories, May 1983.

The International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects was convened in Claremont, California, from October 19 to October 22, 1982. It was organized by Sandia National Laboratories for the United States Department of Energy. Representatives from the six major international projects--Themis (France), Sunshine (Japan), IEA/SSPS (Spain), Eurelios (Italy), CESA-1 (Spain), and the Barstow Pilot Plant (USA)--exchanged information on their respective central receiver plants. This document contains the papers presented at the Workshop, as well as summaries of the four group sessions and the final panel discussion.

2.11 Accuracy of the Barstow Solar Thermal Pilot Plant Cost Estimates, SAND 83-8217, L. G. Radosevich, Sandia National Laboratories, June 1983.

The 10 MW_e Solar Thermal Central Receiver Pilot Plant, located near Barstow, California, is the world's largest solar-powered central receiver plant. The plant, a first-of-a-kind for the United States, is a joint effort of the U.S. Department of Energy (DOE) and the Associates, composed of Southern California Edison, the Los Angeles Department of Water and Power, and the California Energy Commission.

Technology development for the Pilot Plant began in 1975, and the Pilot Plant site and utility partners were selected in January 1977. Several conceptual designs of commercial- and pilot-scale systems and component and subsystem experiments for each of the major subsystems were completed in mid-1977. Based on the results of these designs and experiments, technologies for each subsystem were selected for further development and incorporation into the Pilot Plant. Physical construction began in September 1979 and was completed near the end of 1981. Turbine roll, which resulted in the first net transfer of power to the Southern California Edison grid, occurred on April 12, 1982.

Cost estimates for the Pilot Plant were developed prior to and throughout the course of the project (see Table I). It should be noted that during this time the original plant sizing objectives have remained unchanged: (1) 10 MW_e power to the grid from the receiver; (2) approximately eight hours and four hours of 10 MW_e operation on the summer and winter solstice, respectively; (3) 28 MWh_e of thermal storage capacity; and (4) seven MW_e power to the grid from thermal storage. Scope reductions were implemented, however, when the cost estimates exceeded available funding. The major reductions were the deletion of a semi-automatic and automatic control capability and deferral of some start-up testing. Both will be restored in FY83 and FY84 with operating funds.

The first Pilot Plant cost estimate, $115M, was developed prior to the completion of conceptual designs and prior to site and utility partner selection. At the present time, the total estimated cost is $140.7M ($119.7M for DOE and $21.0M for the Associates). This cost is 22% higher than the initial estimate. The major factors affecting the increase are: (1) unexpectedly lengthy procurement procedures which caused schedule slips and thereby increased costs due to inflation; (2) higher-than-expected inflation; and (3) fabrication and construction problems for which an insufficient cost contingency existed.

Considering the great difficulty in predicting inflation rates over the past few years, the Pilot Plant cost estimates have held up remarkably well. For example, if annual cost outlays are deflated back to constant 1978 dollars based on an 8% inflation rate, then the real costs of the Pilot Plant increased only 9% relative to the first cost estimate. Real cost increases, based on 10% and 12% inflation rates, were only 6% and 3%, respectively. Inflation rates from 1978 to 1981 averaged about 10.2% so the Pilot Plant real costs have increased only slightly.

The accuracy of the Pilot Plant cost estimates is especially striking when compared to other first-of-a-kind energy process plants. For the ten plants studied, real cost increases for all but one had more than doubled and for several had more than tripled. The real cost increase for the Pilot Plant is so low that a cost curve would be almost horizontal.

2.12 Solar Thermal Central Receiver Cost Data Management System (CDMS), Final Report, J. Weingart and P. Bos, Polydyne, Inc. and Associates, April 1983.

The Cost Data Management System (CDMS) is a highly sophisticated, powerful, flexible and interactive computer program for cost data archival and retrieval, cost engineering and analysis, cost comparison and project management. It is currently operational on the Digital Equipment Corporation (DEC)* VAX-11/780 minicomputer using the VMS* operating system. The CDMS was developed by Polydyne, Inc. and Associates, in collaboration with Raymond Kaiser Engineers (RKE), for Sandia National Laboratories, Livermore (SNLL). The CDMS was developed to provide SNLL with a tool to manage cost data for the Solar Thermal Central Receiver (STCR) program. However, it is in no way specific to a specific power generation technology. The CDMS is compatible with the needs of the A&E industry for cost engineering and cost estimating, as well as with the needs for program and cost management within DOE, the Electric Power Research Institute (EPRI) and the utility industry in general.

The CDMS was developed to meet the needs of the following types of users:

- o Program managers,
- o Data base managers,
- o Economic and financial analysts,
- o Cost engineers, and,
- o Cost estimators.

It is generally quite difficult to establish a detailed and consistent overview of the evolution of cost estimates and construction costs for new technologies. In the best of cases, the detailed trail can be recreated only by laborious review of written reports. At worst, the essential information may reside only in informal working notes and files or not at all. Moreover, if a number of independent cost estimates are being conducted for a set of related technologies, such as solar thermal repowering of conventional generation facilities, the lack of a consistent set of procedures for cost estimation and cost reporting may make direct and meaningful cost comparison of the alternatives extremely difficult.

An important feature of the CDMS is that it permits the creation of an audit trail. In the business and financial fields, the notion of a trail is an integral part of professional auditing practices, thus permitting complete audit of the information by people other than those responsible for the development of the cost data. The concepts of a trail and established cost data auditing procedures are especially relevant to cost

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accounting for advanced energy systems, and the CDMS incorporates the necessary capabilities to establish such an audit possibility. The CDMS also provides a mechanism for standardizing cost reporting for a set of advanced technologies. Specific formats for cost reporting can be specified for contractors in advance, and the ease of updating the cost data bases created using CDMS makes possible close monitoring of cost estimates and incurred costs during the project construction phase.

Implementation of the CDMS will not require that cost estimators, cost engineers or others will have to change the way in which they conduct their work. Cost estimators could continue to develop cost estimates in hand-written form on coding sheets. The cost data would periodically be input into the CDMS by a person experienced in the use of this software. Cost reports would be printed for checking and editing. The CDMS cost data bases would then be updated as needed. Any time the costs for a specific account or subaccount changed, the entire cost data base would be recomputed and printed out by the CDMS, without laborious recalculation of costs by hand.

3.0 EUROPEAN SOURCES

3.1 EURELIOS, The World's First Large-Scale Solar Power Plant, J. Gretz, Commission of the European Communities Joint Research Centre - Ispra Establishment, Congress Energy 83, Hamburg, April 1983.

EURELIOS, the world's first large-scale Solar Power Plant of 1 MW_e is described in some detail. EURELIOS is a project of the Commission of the Eurpoean Communities, built by a European Industrial Consortium, consisting of AMN and ENEL, Italy; CETHEL, France; and MBB, Germany. The construction of the plant was completed by December 1980. It is linked, since spring 1981, to the grid of the Italian National Electricity Generating Board, ENEL.

Some operational results of EURELIOS are given, for instance, the mirror cleaning strategy. It turns out that mirror cleaning is more cost-beneficial in Sicily than in the desert where surfaces accumulate dirt more slowly.

The costs of solar electricity are considered and also the question of competitiveness with classical electricity. With heliostat figures of $100\$/m^2$, forwarded in the U.S., and co-generation of electricity and process heat, solar thermal systems are likely to be competitive with photovoltaics in terms of energy production costs.

The size of helioelectric power tower plants is limited by tower height and radiation energy attenuation. The optimum may be in the order of 50-100 MW_e.

3.2 <u>Solar Thermal Power Plants, Their Economics in High Alpine Mountains, Dr. Urs A. Weidmann, Verlag Industrielle Organization, Zurich, 1983.</u>

This study gives an introductory overview of solar electrical energy conversion systems, but restricts the subsequent economic analysis to the solar tower or central receiver concept. It is shown that in the investigation of the electricity production characteristics, solar power plants belong to a new category of electrical power producers: weather dependent peak load power plants. In the same way as with conventional, hydro-electric peak load power plants, they could therefore be used to supply the most power to the European grid network when the energy is most needed--i.e., at lunchtimes. Despite weather forecasting, the availability of energy from solar power plants is not so high and not so reliably "on tap" as from hydro-storage power plants. In order to be able to guarantee peak energy, also on bad weather days, then a symbiotic operation of the solar power plant with the already existing network would be highly recommended:

- In fair weather, the water reserves of storage power plants could be preserved to cover the power lost from the solar power plant on days without sunshine.

- Since solar power plants would supply more energy to the grid during a hydrologically bad year than in a rainy year, they would provide a welcomed stabilizing effect on the energy production from hydro power plants.

The following evaluation of a Swiss solar power plant for alpine use is based on the aspects below:

- Meteorological conditions,

- Geographic and topographical conditions,

- Social issues (environmental, touristic, military, etc.).

The major part of this dissertation, the economic analysis, is based on these initial considerations.

In order to be able to layout the complete solar power plant and its peripherals at an economic optimum, a technical and economic model has been simulated with the computer. With the aid of an optimization program for non-linear systems, it has been possible to examine the optimal power plant configuration and its sensitivity to parameter changes.

The question of investment decision to realize a solar power plant was tackled with well-known present day methods from the theory of investment calculations. Included were all expenditure and profits during the construction and operation, discounted back to the reference year 1980.

The resulting electricity production costs are therefore tariffs, which would have had to have been paid in 1980, for weather dependent peak load energy from solar power plants, such that, taken over the lifetime of the power plant, neither profit nor loss would be incurred. These results demonstrate that a solar power plant on a 20° south facing slope in southern Wallis or Tessin and at an altitude of 2300 m, would have a minimum energy production cost of 14.1 cents/kWh (1 cent = 1/100 sFr) (the assumption was made that the plant under consideration was not a prototype power plant, but the tenth commercial plant of a specific type).

The interpretation of the results may be summarized as follows:

- Smaller land areas and lower installed turbogenerator powers rapidly increase the energy production cost, i.e., "economy of scale" would result in an optimal power plant size for typical Swiss boundary conditions in the region of 300 MW_e generator power.

- A restriction of the land area, e.g., mountain chains, would only cause a modest increase in the tariffs as long as the plant layout is optimal and the minimum land area of approximately 2 km^2 is available.

- It is important to have a shallow horizon angle, i.e., relatively low mountain ridges in the sunrise and sunset region. In addition, a relatively long plant lifetime and also reasonable interest rates are essential for a low electricity price.

The investigation showed that thermal solar power plants could not yet be economically employed in the Swiss Alps even if they have been designed for optimum economy. Electricity from a commercial solar power plant would be some 50% more expensive than the price dictated by the present day market as being acceptable for equivalent energy. It could, however, become more interesting should there be a continued increase in the electricity demand in Switzerland, particularly in the case of increasing resistance against the expansion in the nuclear or coal-fired power station sectors. The potential of approximately 40 km^2 land, which would be available for the economic usage of solar power in the Swiss Alps, could compare favorably in power output to either four coal-fired power plants or one nuclear power plant of the size of 1200 MW_e.

3.3 Economics of Solar Process Heat in the Temperature Range 100°C to 300°C, Karl Amannsberger, MAN-Neuc Technologik, Munche, International Solar Energy Society, 1982.

Solar farm plants, used to produce industrial process heat to cover the high energy demand in this area, are one of the most promising applications in the solar technology especially in the temperature range 100-300°C. Economics calculations using the dynamic cash value method show that solar process heat plants in southern Europe will be economically competitive in the early 1990's. Criteria used in the calculation were recapture time,internal interest rate and average energy costs. These results were subject of a sensitivity analysis. Subventions in the form of investment capital or low-interest loans are a suitable means to accelerate the approach to the point where an economical investment takes place. The world-wide commercial market could be entered already at the end of the '80s if it would be possible to succeed in further demonstrating the technical reliability of such plants, as well as to gain the trust of the users in the new technology, as well as to reach the cost goals by the use of mass production technology.

3.4 Economical Progresses of Solar Thermal Power Plants, Dr. F. K. Boese, Interatom, 5060 Bergerer-fladbach 1, International Solar Energy Society, 1983.

There is a multitude of different power plant concepts presently available to produce solar thermal electricity for a series of diverse application areas. An evaluating comparison regarding their economics is not yet possible. Therefore, this is only an attempt to present the presently achieved status, to explain cost structures, and to show development trends. Even if we consider the presently incomplete state of knowledge, we predict that solar thermal power plants will have a good chance to become competitive, especially if they can be run in a power-heat-coupling mode. In this area they have a basic advantage versus photovoltaic systems. In comparison to the present prototype plants, it will be decisive for the lowering of costs, that practical experiences will be collected from the described plants, and that a sufficient quantity of essential components can be mass produced.

3.5 Methods for the Economical Evaluation of Regenerative Energy Sources, Dr. Fredy Jager, Fraunhofer-Inst., Karlsruhe, International Solar Energy Society, 1982.

Methods of investment calculation can be used for the analysis of the economics of energy technological plants. This report describes the static and dynamical methods of the investment calculation as well as aspects of their application to energy technological plants. Especially the dynamic methods are recommended to be used. With these methods it is possible to encompass quantitatively the changes in costs and returns during the investment duration as a function of time. This is of special importance for the mostly capital intensive systems which use regenerative energy sources. Consideration of the future price increase of conventional energy systems is of essential importance for the economics of regenerative energy plants. Since the various methods provide statements which are of importance for different decision situations, we recommend the combined use of multiple methods. Because of the general uncertainty of data, the calculations should be supplemented with sensitivity analyses.

3.6 Contributions to the Economics of Electric Energy Production from Solar Energy, Report No. 387-1-79, Dr. Horst Ellgering, DLVFR, June 1979.

The world energy situation offers three options: coal, nuclear or solar. The advantages of solar energy are that it is decentralized, that it is suitable for areas with low industrialization, and that it is not part of the electric utility infrastructure.

Major difficulties are that solar energy has both limited availability and low energy density.

To overcome these difficulties, a high technical investment is necessary, the costs depending on the system site and type. Estimates range from 7,000 to 30,000 DM per installed kilowatt of electric power. Such investments ask for electricity production costs between 0.4 to 1.5 DM/KWh where, as a rule of thumb, it is expected that 0.05 DM/KWh relate to 1,000 DM investment if an annual full-time use of 3500 h and a lifetime of 20-30 years is anticipated.

Solar generation and storage systems alone do not provide the energy security presently being standard in western countries. Normal use of solar energy for electricity production is in concert with other primary energy carriers. Especially in the first decades of application it will serve primarily to save fuel.

The time, when the use of solar energy to produce electricity will be competitive, is connected to the price development of fossil fuels. It is assumed that this will be the case in the first decade of the next century considering all uncertainties of such prognoses. There are, nevertheless, special applications in which such competitiveness already exists today. The number of applications will increase considerably, especially if photovoltaics can be applied or if integrated energy systems, such as SONNTLAN, can be constructed.

It is especially stressed that the insolation data of moderate regions such as middle and northern Europe do not allow as economical production of electricity from solar energy as those areas with high insolation. This is especially valid for solar thermal energy conversion; the thermal radiation energy of the sun is only suitable here for the production of warm water used in consumption and heating. Nevertheless, it is necessary for the industrial nations to address solar technology, even if this cannot be used in their own country. The expected future energy situation will force a (rethinking) reevaluation of this area and will ask for a north-south cooperation in which the northern partners offer technical know-how and the southern partners offer location, personnel and later electrical current. In the long term, it is of interest to produce hydrogen as a "secondary primary energy carrier" from solar energy. Not only will the aspect of energy security be addressed via the mentioned cooperation, but also the considerable export possibilities should be a convincing reason for the industrialized countries to concern themselves in an intensive way with the technology of solar energy applications.

3.7 Solar Thermal Power Plants, Technical and Economic Possibilities in Austria, Faninger, G., et al, ASSA FA-9, Austrian Solar and Space Agency, May 1979.

The meterological, geographical, technical, energy-economic, and economic possibilities of solar electricity generation in Austria were investigated under a contract of the Federal Ministry of Science and Research (BMWF) to the Austrian Solar and Space Agency (ASSA). It has been shown that the land required for a large-scale use of solar thermal power plants in Austria could be made available, that is to say, essentially without limitation upon Austria's agricultural production. However, the number of adequate locations at high altitudes, which are meteorologically favourable especially in winter, is found to be limited.

A 40 MW(e) solar power tower with an areal requirement of 0.8 km^2 in the Alps as well as a 200 MW(e) solar tower at a site of 4 x 1.25 = 5 km^2 in low lying area were studied, each laid out for two hours of thermal storage. For the latter plant, annual electricity generation cycles were calculated by means of a computer program using meteorological data of Vienna. Such calculations for the Alpine plant had to be based on meteorological estimates.

The period of utilization in the flat region is shown to be only about 1100 hours per year; it may be slightly longer in the Alpine region. Since the electricity generation is confined to the summer and immediately preceding and following periods, annual hydrostorage installations are needed for a constant overall annual electricity generation. The possibilities of hydrostorage are limited orographically, even in Alpine Austria. In total, high electricity generating costs result, above all because of the short period of usable sunshine hours. The period of utilization would be three times as long if such solar power plants were set up in the proximity of dry equatorial zones, facilitating more economic uses of solar power even in the case of long-distance transportation.

More conclusive statements would require additional measurement of direct insolation at locations in flat areas and, in particular, in Alpine regions. Furthermore, a detailed study of a specific site as well as the development and testing of an Alpine-proof heliostat are recommended. With respect to future export chances of Austria's industry, consideration of the establishment of a pilot plant in Austria is suggested.