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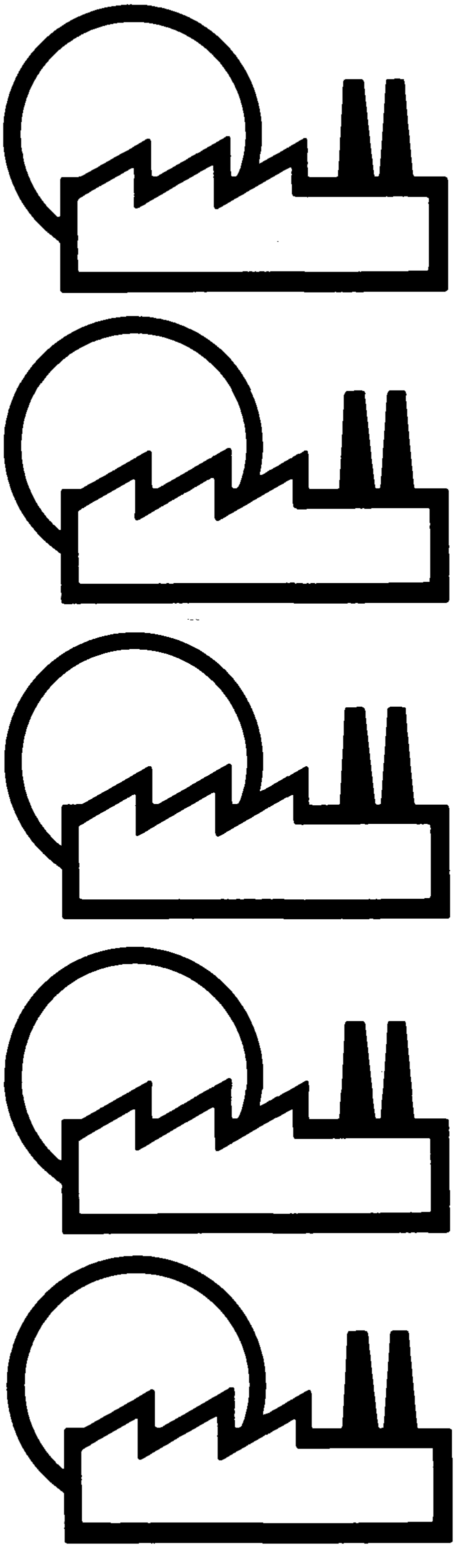

Solar Industrial Process Heat Conference Proceedings

**October 31-
November 2, 1979**

Sponsored by:
**Solar Energy
Research Institute**
for the
**U.S. Department
of Energy**

Location:
San Francisco Bay Area

NOTICE

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SOLAR INDUSTRIAL PROCESS HEAT
CONFERENCE PROCEEDINGS

OCTOBER 31 - NOVEMBER 2, 1979

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FOREWORD

The fourth annual Solar Industrial Process Heat Conference was organized to promote interaction between researchers and potential users of solar industrial process heat systems, to evaluate the status of existing industrial process heat projects, both privately and federally funded; and to review the technical readiness and expected future development of Solar Industrial Process Heat systems and components.

This 2-1/2 day conference brought together researchers, solar system manufacturers and installers, industrialists, planners, and government program participants on the state, regional and federal level. The meeting successfully met these objectives, as evidenced by the papers and discussion summaries contained in this volume. In addition to state-of-the-art information on technologies and field test programs, workshops and an industry user panel provided valuable forums to discuss the problems and needs of this burgeoning application of solar energy systems.

The conference was sponsored by the Agricultural and Industrial Systems Branch of the Department of Energy. The support of the Branch Chief, Jimmie F. Dollard, and program managers, William W. Auer and Jerry M. Greyerbiehl was enthusiastic and constant. Many individuals worked hard to make the conference both useful and smoothly run. The technical merit of the conference, of course, rests on the contributions of the speakers, poster session authors, session chairman and panel members, to whom we are grateful for their professional excellence and approach. The conference ran smoothly only because of the talented organization of the SERI Conferences Branch and the preplanning of the Conference Steering Committee. We gratefully acknowledge, therefore, the work of Kate Blattenbauer, Conference Coordinator; Vicky Curry, Branch Chief; Donna Post and Zo Milne. The Steering Committee provided the direction, insight and work necessary to address the important issues, select an effective format, and organize the contributors. They were Rosalyn H. Barbieri, Jet Propulsion Laboratory; Alan B. Casamajor, Lawrence Livermore Laboratory; Shelly Gordon, Chilton Engineering; James I. Mills, Idaho National Engineering Laboratory; William Nettleton, Department of Energy/San Francisco; Duane E. Randall, Sandia Laboratories, Albuquerque; and Vern Rees, Suntec Systems, Inc.

To all of these and to the conference participants, we thank you for your support and look forward to an even stronger conference in the fall of 1980.

DW Kearney

Dr. D. W. Kearney

Stephen L. Sargent

Dr. S. L. Sargent

Conference Co-Chairpersons

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Introductory Session

DOE Solar Thermal Power Systems Program

Gerald W. Braun

Acknowledgement

The author gratefully acknowledges the help of Dr. Howard Coleman and Messrs. Robert Anan, George Kaplan, Martin Gutstein, and William Hockheiser of the Department of Energy and Mr. Ronald Edelstein of PRC/Energy Analysis Company, whose critical comments on drafts of this review led to substantial improvements and clarifications.

DOE SOLAR THERMAL POWER SYSTEMS PROGRAM

INTRODUCTION

The DOE solar thermal power systems program supports development of concentrating mirror/lens heat collection and conversion technologies, for both centralized and dispersed applications. Photovoltaic electric systems using concentrating mirrors also draw on the technology base being established in this program. Beyond the nonconcentrating flat plate collectors now used for water heating, thermal conversion based on concentrating collectors is the most direct method of harnessing solar energy. The concentration of sunlight is necessary for applications requiring temperatures above 200° F. It now appears that thermal concentrator systems may be economically preferable to flat plate systems in many lower temperature applications.

Concentrator systems utilizing conventional materials (glass, steel and concrete) can produce heat from solar radiation over a range of temperatures, from ambient to 2000° F. These systems, modular over a wide range of sizes, are directly adaptable to existing equipment and processes requiring steam and hot air, including factories and utility power plants.

The inherent high temperature capability of these systems will allow thermal concentrators to become a major factor in all sectors of the national energy market. They will be used to produce electricity, provide high grade heat at its point of use in industrial processes, provide heat and electricity in combination for residential and commercial needs, and ultimately, drive processes for conversion and production of fuels for the transportation sector. The versatility afforded by solar thermal concentrator systems significantly expands the potential for the solar energy technologies under development by DOE to reduce our nation's requirements for imported fuels (figure 1).

Scientific feasibility of high concentration solar thermal systems was established in the late 19th century. In the early 20th century concentrating collectors were operated with small heat engines and pumps. As was the case with flat plate collectors, the early concentrator systems found no permanent niche in an expanding energy market based on cheap and abundant fossil fluids, but fuel scarcities and price increases have improved the conditions for their commercial acceptance and industrial implementation. Acceptance is also aided by mass production techniques and computer control technologies to reduce capital and operating costs. Better materials are available to improve system performance, reliability, and life expectancy.

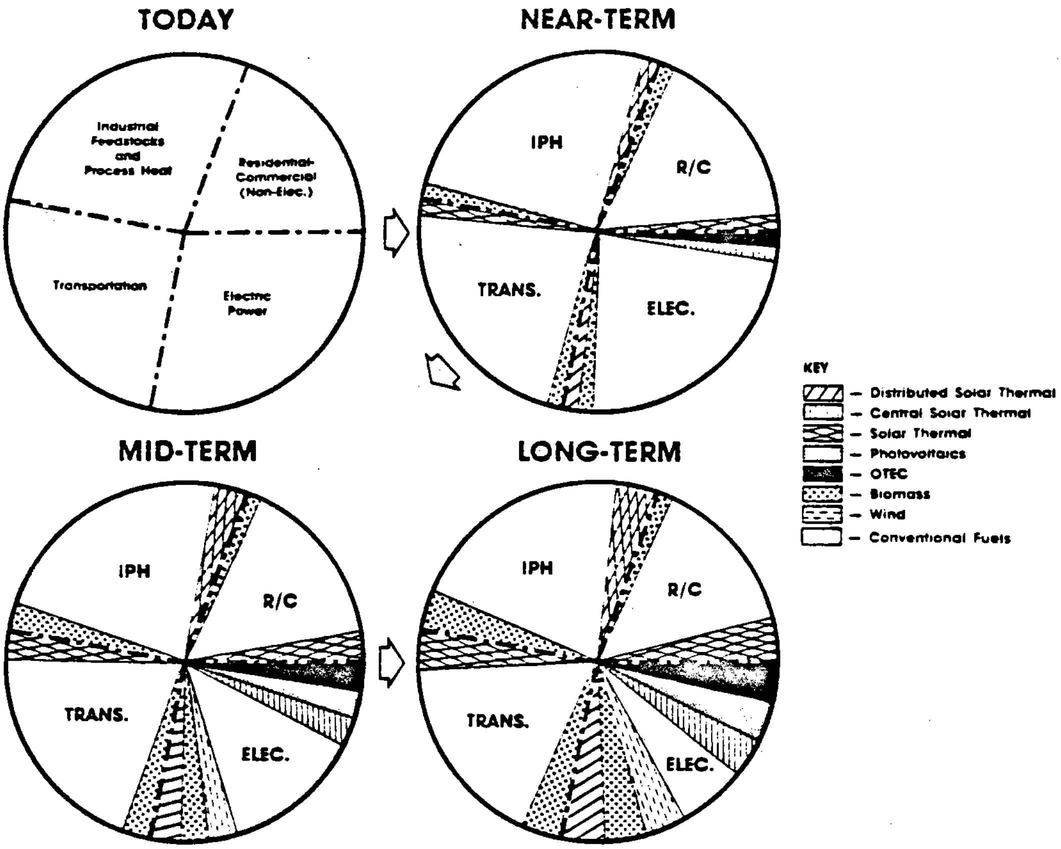

Figure 1. Market Potential

As a consequence of the ongoing program, engineering feasibility issues are rapidly approaching resolution. The strategic focus of the DOE program is shifting to system cost readiness. Concentrating thermal collectors are already entering the residential and commercial sectors of the U.S. energy market and show high potential in the electric and industrial sectors.

Evolution of the Federal Program

Early assessments of solar options established solar heating and cooling and solar thermal conversion as having major near-term potential. Work on thermal, collector, and system technologies gained early momentum. The solar thermal program reached a level of roughly $100 million per year in FY 1978 and 1979. Its funding history is indicated in figure 2.

SUMMARY OF SOLAR THERMAL FUNDING
(in millions)

	FY75	FY76 and Transition Qr.	FY77	FY78	FY79	FY80
Large Power			21.5	21.8	27.0	64.1*
Small Power	13.2**	26.9**	20.1	28.1	28.0	33.5*
Advanced Technology			7.4	10.2	14.0	23.4
Construction/Capital Equipment	--	6.4	18.1	44.0	31.0	--
	13.2	33.3	67.1	104.1	100.0	121.0

* Includes Capital Equipment/Construction Funding

** Classified as R&D funds under ERDA

Figure 2. Funding History

Solar thermal power systems is now one of five solar development programs reporting to the DOE Assistant Secretary for Energy Technology through the Program Director for Solar, Geothermal, Electric, and Storage Systems. Solar thermal and ocean systems programs comprise the Division of Central Solar Technology. Photovoltaics, wind, and biomass programs comprise the Division of Distributed Solar Technology. Commercialization programs for solar heating and cooling and agricultural and industrial process heat report to the Assistant Secretary for Conservation and Solar Applications.

In the early 1970's, central station electric power applications were accorded high priority in federally-funded energy research and development programs (then geared to long-term improvements in energy supply technology). This emphasis provided an excellent focus for the development of central receiver ("power tower") systems which are readily adaptable to conventional utility turbine plants. The relative merits of distributed receiver concepts tended to be measured against the needs of large-scale applications. As a consequence, distributed receiver development received less emphasis.

Subsequently, a clearer perception of the market potential for smaller scale systems converged with the increasing sense of urgency for development of energy options. This led to the creation of a program element having the mission of developing smaller scale solar thermal systems for dispersed power applications. Efforts supporting dispersed and onsite solar thermal system applications are now on an equal footing with comparable efforts in support of larger, more centralized applications.

The overall program is now structured around the major concentrator approaches that can serve these two broad classes of applications. These include linear distributed receivers, (parabolic troughs and fixed hemispherical bowls), point focusing distributed receivers (parabolic dishes), and central receivers. Advanced technology, generic to all concentrator systems, is aggregated under a separate element. The program organization shown in figure 3 has emerged hand-in-hand with decentralization of program and technical management. Decentralization has been motivated by the inherent complexity of managing a program having diverse technical and applications options. In decentralizing program management, efforts leading to applications experiments have been assigned, where possible, to DOE field offices. Engineering development responsibilities have been assigned to Sandia Laboratories and the Jet Propulsion Laboratory (JPL). The DOE Solar Energy Research Institute's (SERI) role in the program began with an assignment to manage the advanced technology element.

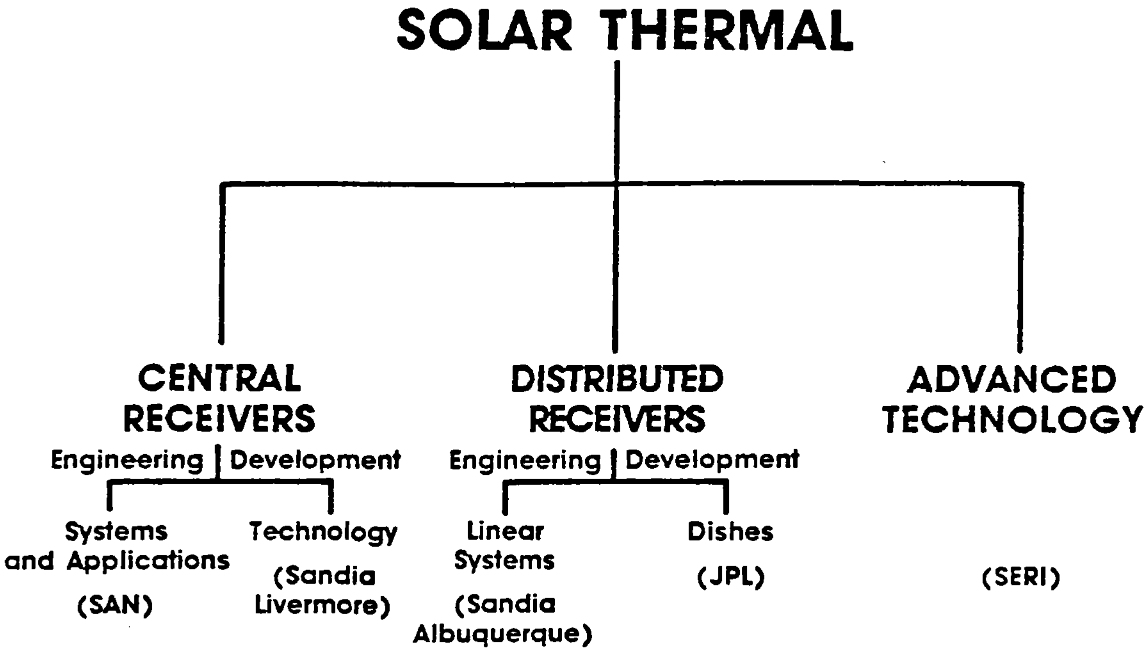

Figure 3. Program Organization

The new structure provides clear boundaries for decentralized management and allows research and development activities for each concentrator approach to be prioritized within a clearly defined budget. Industry is strongly urging the delay of narrowing technical options within the concentrator programs until critical technical issues are resolved for each subsystem. Although this may not continue to be possible, in all cases the new structure provides the most comfortable framework for making necessary programmatic decisions.

Priorities among concentrator options can, in turn, be established based on assessments of the best market opportunities and potential energy displacement impact of these different technical approaches. In order to carry on higher pay-off and/or lower risk efforts at a critical level, conscious decisions can be made to forego certain market opportunities and associated concept developments. The program may face these decisions within the next two years.

Accordingly, a high priority has been assigned to completing studies aimed at characterizing potential markets and identifying concentrator systems having the best competitive prospects within these markets. In addition, studies will be initiated later this year to better define system costs and technical capabilities needed to penetrate key markets. Studies will also be initiated to estimate the R&D expenditure needed to establish market readiness of the most promising candidate systems. Building on these efforts, a major market penetration assessment will be launched. It will identify appropriate program funding levels and the effect of different funding levels and paths. These assessments seek to identify systems offering the earliest and greatest market impact at the least federal expenditure.

Markets

Anticipating budget constraints and the resulting difficult decisions, the solar thermal program strategy will be critically dependent on reliable assessments of potential markets. The electric market and its requirements are well understood. Our understanding of the equally large industrial process heat (IPH) and cogeneration markets is poor at this time. Their importance to the program adds impetus to ongoing efforts to identify favorable early IPH applications. Although IPH and electric power applications may use the same optical configurations, variations which might be deemphasized for electric power could be fundamental to IPH applications.

For example, thermally-connected, high-temperature, distributed receivers may be best for small system IPH applications. As another example, large, high-temperature, gas-receiver technology is an option for bulk thermal and electric power generation involving higher risk and larger R&D expenditures than liquid or steam receiver alternatives. Nevertheless, this technology will be needed in order to serve many important applications above 1000° F which represent a substantial share of the present IPH market. As a third example, for industrial heat, an onsite fossil back-up capability will, in general, be essential to maintain necessary levels of plant reliability and, thus, provide production continuity. Relative to grid-connected electric applications, there is substantially less motivation to develop technology for new solar/fossil hybrid systems. Thermal storage can provide buffering; utility electric systems, intrinsically hybrids, do not require each solar plant to have built-in fossil back-up.

Application requirements reward certain capabilities and penalize certain limitations of the feasible concentrator geometries. Temperature, size, and geography are important market-related dimensions. Achievable concentration ratios impose practical limits on the temperature of deliverable heat, inherent concentrator system modularities span four orders of magnitude, and effects of latitude and atmosphere on optical performance are more limiting to some concepts than others. Understanding of these considerations is increasing. At present, it appears likely that each of the major concentrator system options will find a sector of the energy market in which its unique technical characteristics afford it a significant competitive advantage relative to others. For some major applications it is too early to suggest which approach will compete most favorably. Significantly, an incentive to carry on development of each concentrator approach in order to maximize overall market capture potential is suggested.

Nontechnical considerations will also be critical in prioritizing technical options in relation to market potential. Major potential markets will differ in terms of:

(1) user's financial decisionmaking criteria,
(2) relative uniformity of size and technical requirements (at stake is the degree of system and component standaridization that is possible and the amount of special design effort required for each project),
(3) land cost and availability for both retrofit and new installations,
(4) capital formation capability of potential users,
(5) relation of market size and growth to geography,
(6) cost and availability of conventional fuels, and
(7) applicable regulatory and tax constraints.

Strategy and Implementation

The DOE Solar Thermal Technology Program should be the catalyst in the formation of a self-sustaining industry. There are signs of movement in this direction. Of course, there are technical, institutional, and cost barriers in the path, but U.S. industry can overcome them.

What beneficial role can DOE play? DOE can change the "can" into a "will" by sharing and reducing (and in some cases eliminating or assuming) risks that confront potential suppliers and users. This should be the program's unifying strategic theme. The relevance and importance of program elements and projects should be judged in terms of their effectiveness in reducing uncertainties in system performance, in reliability, and in cost (initial and operating) to levels at which private commitments to production and purchase of equipment can be made under conditions of acceptable risk.

To reach its goal by the most direct route, the program should look for paths to early markets. High concentration systems have the inherent virtue of being adaptable to much of the existing national electric energy supply system and facilities providing industrial process heat. This suggests a strategy in which concentrator industries can be aided in establishing retrofit markets through DOE cost-shared applications experiments. Indeed, such a strategy has been initiated for the central receiver program and will be considered for each of the other concentrator efforts as well.

Within this strategic framework, concentrator system engineering development efforts are proceeding thorugh sequential overlapping stages. These include the development and fabrication of concentrators, characterization of their performance based on prototype tests, completion of subscale field experiments and pilot plants, development of mass producible designs, and validation of these designs at DOE test facilities. Parallel efforts are underway to define appropriate second-generation critical system experiments and engineering demonstrations. Application experiments are selected to provide experience in markets of early opportunity and designed to maximize the sharing of experience with potential users.

A program of advanced technology development which emphasizes improvement and characterization of key materials and advanced development of thermal subsystems, including energy storage and transport, high temperature heat receivers, and small heat engines parallels the engineering development activity. In addition, studies and experiments are being conducted to establish candidate solar heat-driven processes for production of transportable fuels. The primary strategic purpose of the advanced technology effort is to provide a technical basis for concentrator system improvements and applications that expand the market potential of these systems.

Goals

Consistent with penetrating major energy markets, cost goals for all concentrators systems have been established. In general, 1990 goals (in present dollars) are in the range of $1,000 to $2,500 per kilowatt, depending on system capacity factor and credits for heat production. This roughly equals five dollars per million Btu for heat. When established, goals for fuel derived from thermochemical processes will be in the range of five to ten dollars per million Btu. These goals are based on market value and, in turn, provide a framework in which to establish targets for subsystem costs. In particular, the aim is to reduce the cost of heliostats, troughs, dishes and other distributed concentrators to seven to ten dollars per square foot by 1990 and 25 to 50 percent lower by 2000. System and subsystem goals are now under review and will be adjusted based on recent studies, current assumptions, and R&D funding distribution in 1980.

The following sections summarize the programs designed to achieve these goals.

CENTRAL RECEIVERS

Central receivers represent the solar thermal program's most visible technical thrust, and the one which has received the most critical attention. The central receiver concept is applicable to large-scale, high-temperature applications. However, recent studies by Sandia suggest good competitive prospects for the concept in smaller and lower temperature applications. This finding has significant implications for both technology program priorities and the overall commercialization strategy.

10 MW Pilot Plant. The 10 MW central receiver pilot plant, now in the early stages of site activity near Barstow, California, has been the lightning rod of the program amidst the storms of skepticism. Claiming 30 percent of the program's three-year budget between FY 1978 and 1980, the project has been subjected to high level technical review, management audit, and deferral. It has survived intact because: (1) economic prospects for central receivers look increasingly favorable as experience accumulates and cost estimates are firmed up, (2) the management approach established by DOE's SAN Office is sound, and, most importantly, (3) the engineering community and utility industry unequivocally regard it as an essential step on the path to commercial acceptance of central receivers.

The project at Barstow will provide solid data points for cost, performance, and environmental impact projections. It will provide design and operating experience with an integrated plant that cannot be simulated with even the most powerful analytical tools. The project reaches a critical point this fall when preliminary design efforts will be completed, cost estimates become available, and bids for heliostats are evaluated. Selection of the heliostat supplier (between McDonnell Douglass and Martin Marietta) will be based on their quotes and tests of preproduction prototypes now under way at the Central Receiver Test Facility (CRTF) near Albuquerque, New Mexico (see figure 4).

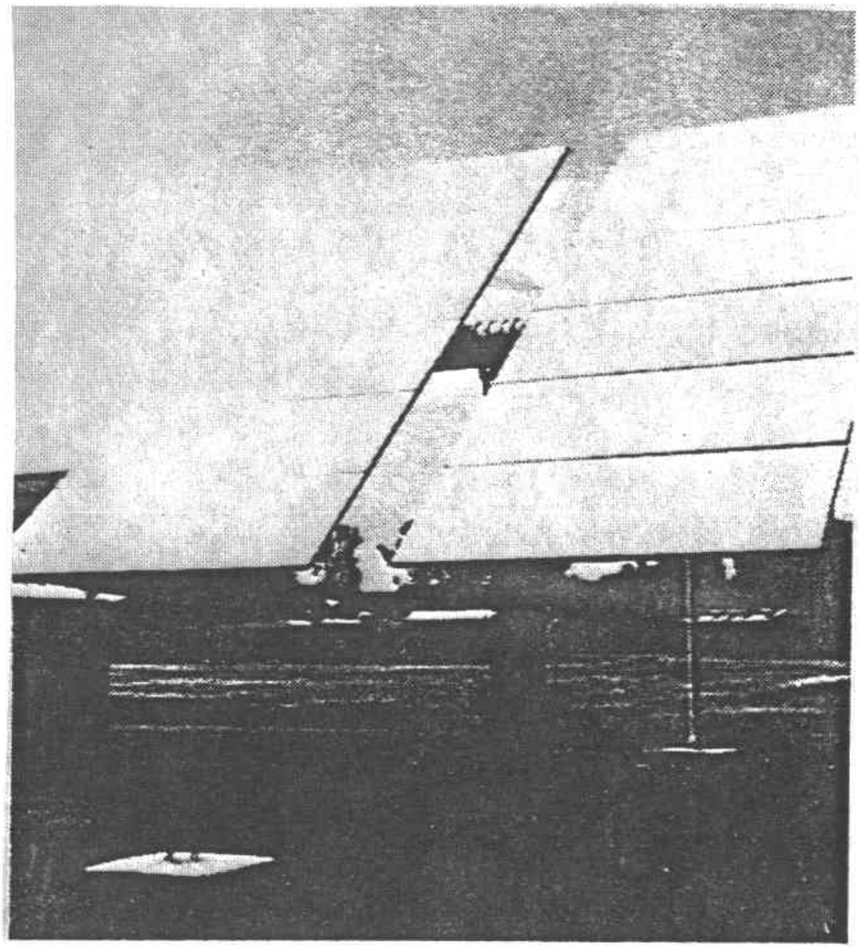

Figure 4. Barstow Heliostat

Repowering. The repowering concept, as illustrated in figure 5, was originally introduced by the Public Service Company of New Mexico. It has captured the interest and imagination of southwestern electric utilities. It involves building central receiver systems adjacent to existing fossil fired steam power plants. Solar generated steam delivered to an existing turbine reduces consumption of oil and natural gas. This market is large enough (several tens of thousands of megawatts of existing oil and gas fired power plants in the southwest) to provide an adequate base for a heliostat industry, even if market penetration is limited by siting constraints to only a few. Directing initial heliostat/central receiver industrialization activities in support of such retrofit applications is responsive to the provisions of the National Energy Act, which constrains oil and natural gas use in large utility and industrial boilers.

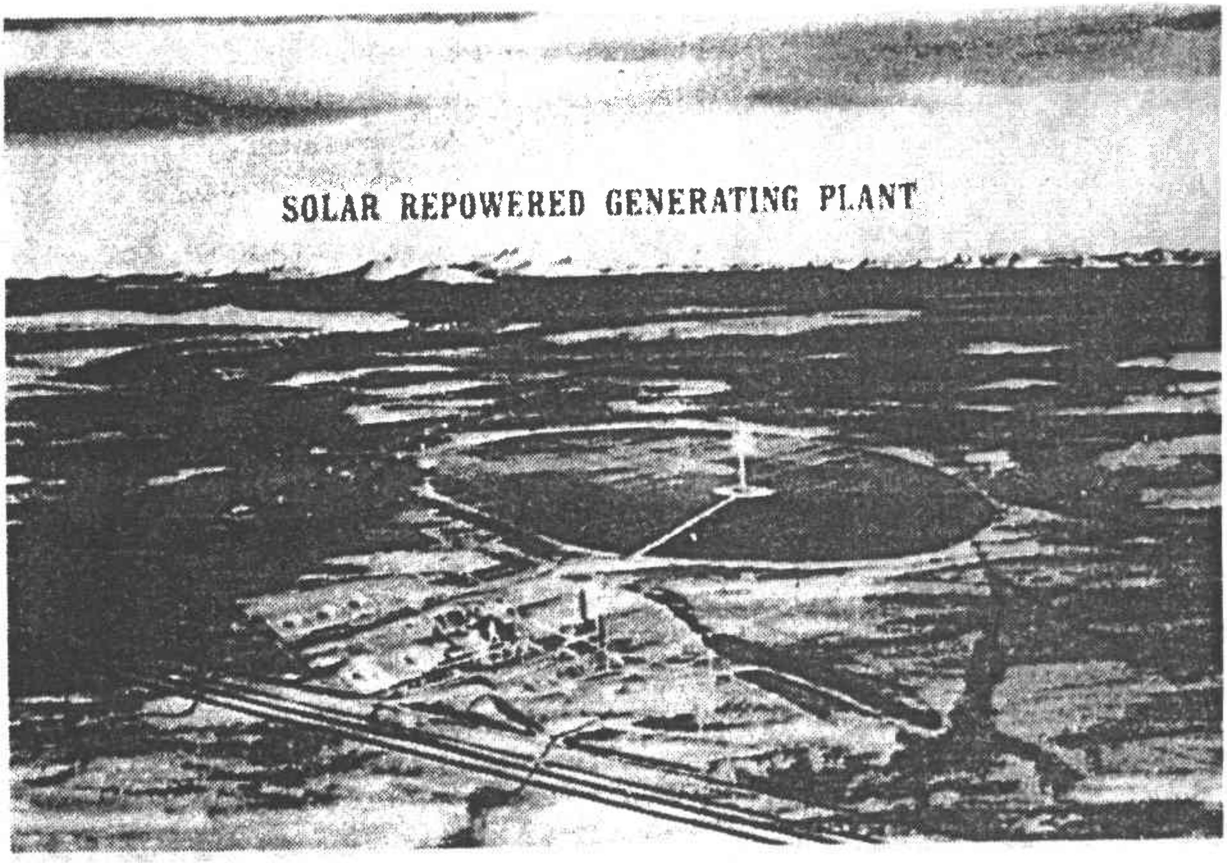

Figure 5. Repowering (Artist's Concept)

Response to a recent solicitation entitled "Solar Repowering/Industrial Retrofit Systems" was excellent. The resulting project definition efforts will be initiated in two categories: repowering and IPH retrofit. Nine-month contracts, to be awarded in September 1979, will involve user/supplier teams developing conceptual designs and site specific project plans. These project definition efforts will allow cost-shared projects to proceed in both categories, subject to funding availability and the results of the central receiver strategy analysis (nearing completion at SERI). Building upon a base of studies already completed, this initiative is closely linked to FY. 1979 contracts to develop and test mass producible heliostat designs by FY 1981. A program opportunity notice to select repowering/retrofit projects for construction is planned for FY 1980. Such projects should provide an initial heliostat market base with no direct federal involvement in heliostat production.

Central Receiver R&D. In parallel with the pilot plant and proposed retrofit projects, central receiver system and component R&D is funded at a level of roughly $25 million per year. Management of systems and applications related efforts has been delegated to the DOE San Francisco Operations Office (SAN). Sandia Laboratories at Livermore provides technical management support to SAN. Management of component (heliostat and receiver) development efforts has been delegated directly to Sandia. These organizations are fulfilling decentralized management roles in an exemplary manner.

The SAN program includes system definition and evaluation related to major potential applications as well as support of the 10 MW pilot plant project office (located near Los Angeles). Conceptual designs of hybrid systems have been completed for bulk electric power applications. Follow-up efforts will focus on solar/fossil hybrid configurations which minimize back-up fossil fuel consumption in IPH applications. Storage-coupled nonhybrid designs will be further evaluated for stand-alone applications through the joint DOE/Bureau of Reclamation assessment of solar power plants in the BuRec hydroelectric based grid.

Project definition efforts related to small scale central receivers for total energy and cogeneration applications are also in the SAN program. These include a rework of the recently completed preliminary design of a total energy system for the Fort Hood, Texas barracks complex and site specific conceptual designs to explore cogeneration applications. The latter effort can build upon gas receiver development funded by the utility industry through the Electric Power Research Institute (EPRI). The EPRI program has been closely coordinated with DOE efforts and has produced two receiver designs with capabilities in the 1500 to 2000° F range; the first of which was recently put through a highly successful series of tests at CRTF, as shown in figure 6.

DISTRIBUTED RECEIVERS

Distributed receiver engineering development efforts are proceeding on the strength of a 30-35 percent share of the total DOE solar thermal power systems budget. The efforts encompass work on parabolic trough, hemispherical bowl, and parabolic dish concentrators and generically related concepts.

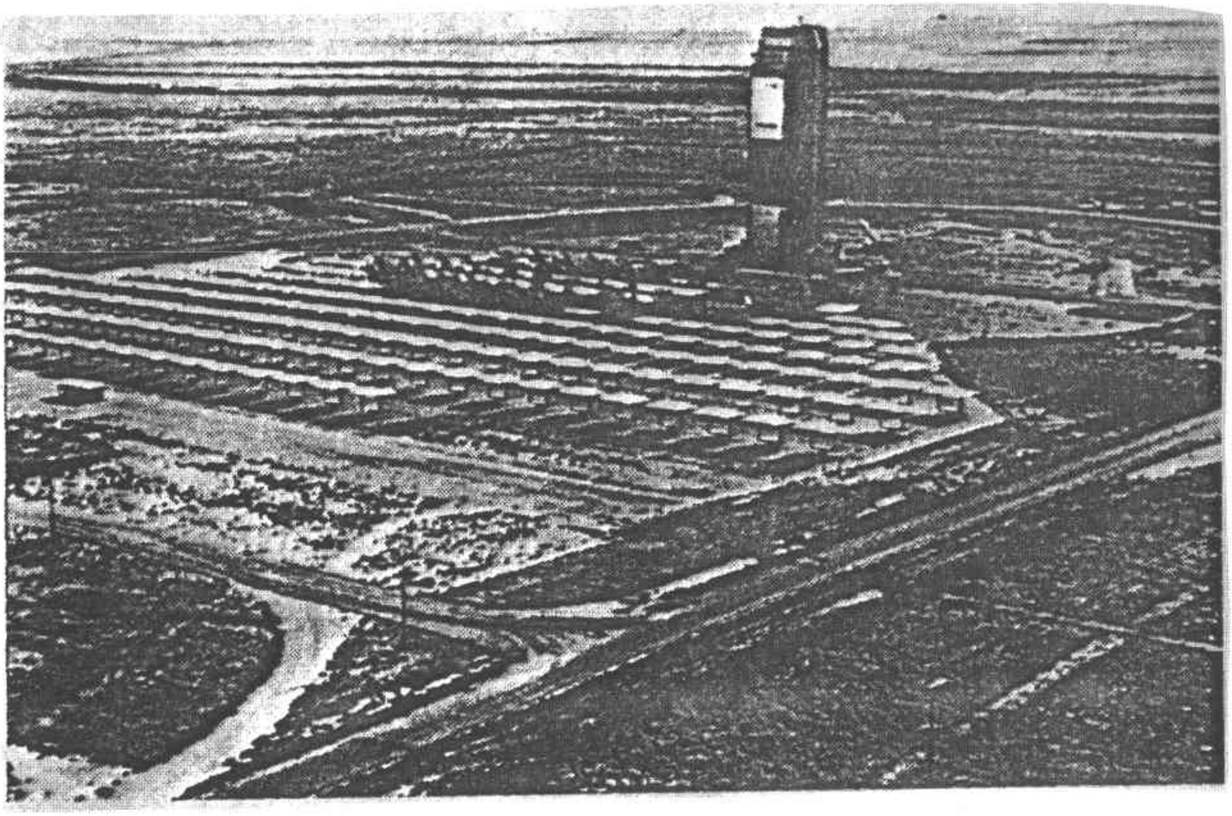

Figure 6. EPRI Receiver Testing of CRTF; Albuquerque, NM

Distributed receiver efforts related to total energy and irrigation pumping applications were initiated in 1974 and 1976, respectively, at Sandia Laboratories and grew to provide a focus for parabolic trough development and early field experiments. Funding of hemispherical bowl development was initiated in 1976 with a case study evaluation of its potential in cooperation with the town of Crosbyton, Texas. About two years ago, development of an intermediate temperature parabolic dish concentrator was initiated by General Electric for a large-scale total energy experiment at Shenandoah, Georgia. Funding of high temperature dish development at JPL was initiated shortly thereafter.

Linear Concentrators. In the linear concentrator area, Sandia Laboratories (Albuquerque, New Mexico), has established a position of preeminent expertise. Attempts are being made to transfer this expertise to potential equipment suppliers. Technology development efforts aimed at high performance concepts with capabilities in the 400 to 600° F range have followed a path of component research and development at Sandia. This has been coupled with system and subsystem test and evaluation activities at the Mid-Temperature Solar Systems Test Facility (MSSTF) operated by Sandia. Figure 7 shows a portion of the equipment of the facility. A large number of concentrator designs developed by potential suppliers have been evaluated at the adjacent Collector Module Test Facility (CMTF). Based on lessons learned in this early design and testing activity, trough concentrator mass producibility studies are scheduled for initiation later this year.

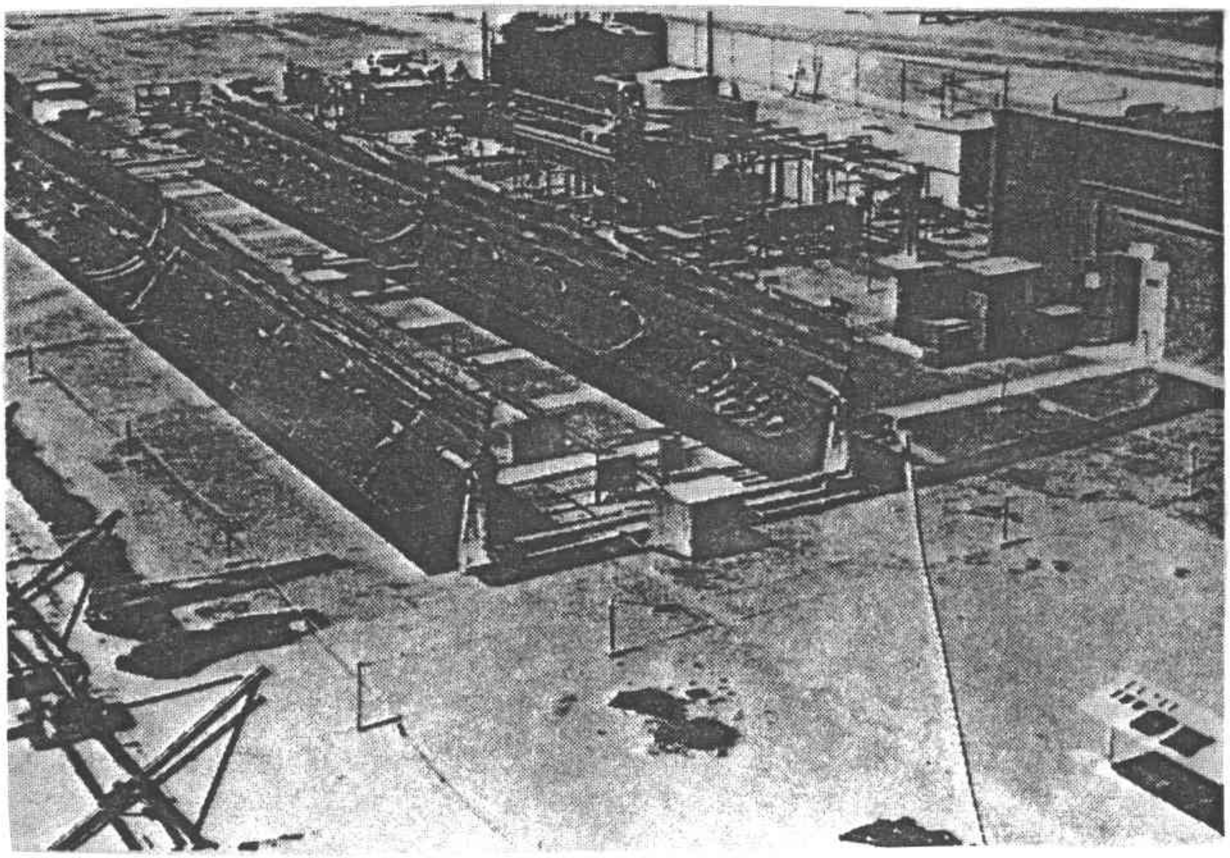

Figure 7. Mid-Temperature Solar Systems Test Facility: Albuquerque, NM

Mid-temperature trough system design and evaluation activities involving potential system suppliers have been focused on three projects: the 25 hp shallow well irrigation pumping experiment at Willard, New Mexico, which was placed in operation in mid-1977 (see figure 8); a large 150 KW deep well irrigation pumping experiment at Coolidge, Arizona (see figure 9), which will begin operation later this year; and, the design of a large (roughly 100,000 square foot) trough collector array for the Ft. Hood total energy large-scale experiment. The trough system design for this military barracks applications, performed by

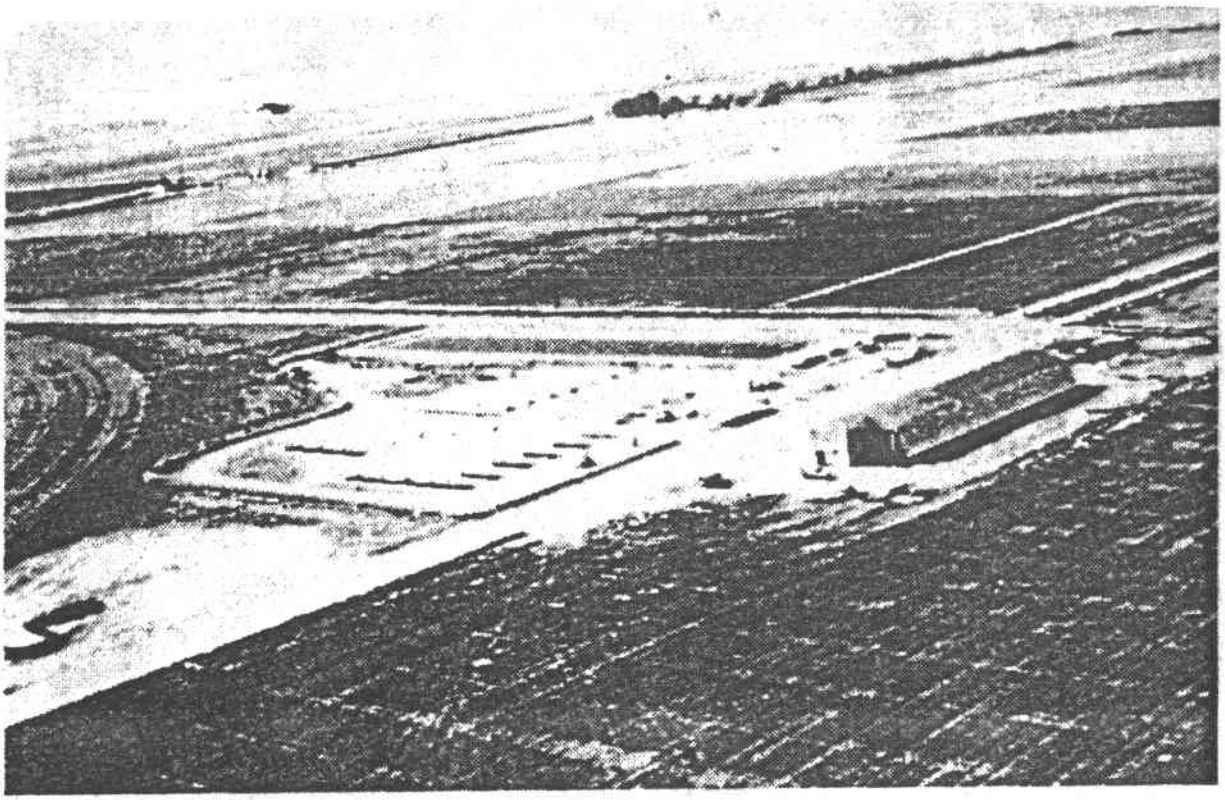

Figure 8. 25 hp Irrigation Pumping Experiment; Willlard, NM

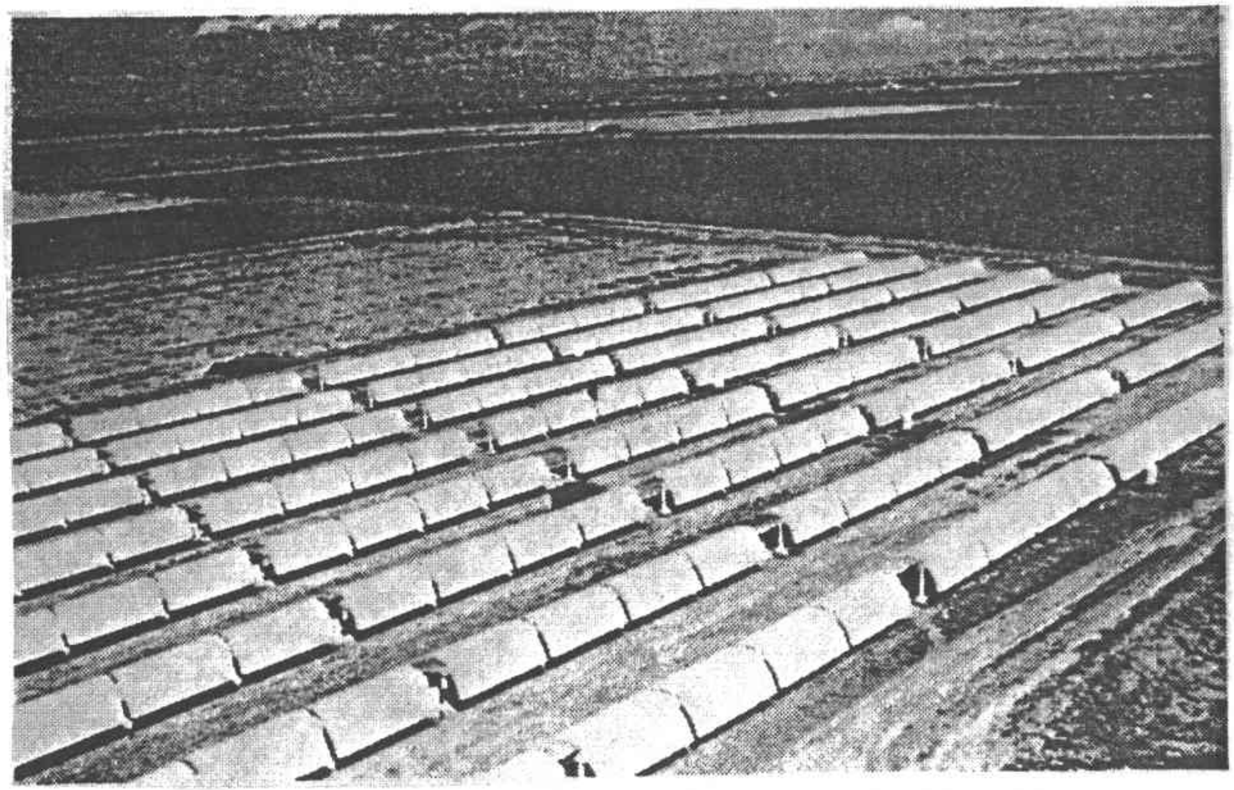

Figure 9. 150 kW Irrigation Pumping Experiment; Coolidge, AZ

an American Technological University/Westinghouse team, was technically satisfactory, but was deferred to explore the applicability of central receiver technology to total energy large-scale applications.

A major project, now under way, which will involve the use of trough collectors to supply steam for enhanced oil recovery is a further step in the direction of demonstrating trough system capabilities in potential near-term applications. This application offers both trough and central receiver system suppliers a potentially receptive market, in view of restrictions on conventional alternatives. At stake is an opportunity to enhance U.S. recoverable domestic oil reserves by billions of barrels.

Conceptual design studies to explore the possible use of higher temperature (up to 1000° F) linear designs for bulk electric power have also been completed. No major advantages over central receivers for systems at the 100 MW scale were identified, but follow-up efforts may suggest favorable applications and avenues of development to improve linear system performance and temperature capability.

Parabolic trough concentrators are already in production for low-grade heat applications. DOE funded IPH demonstrations involving "off-the-shelf" trough technology are being deployed through a DOE program under the Assistant Secretary for Conservation and Solar Applications (CSA). A strategy is called for which connects market development of the emergent concentrator industry with Sandia managed efforts to establish technical and cost readiness of high-performance, high-temperature designs.

The key link will be companies having system level design and hardware experience, who as a result, are in the position to sell integrated "solar boiler" packages. At present, there are fewer of these companies than DOE sponsored system installations. One company, Acurex-Aerotherm of Mountain View, California, has been involved as prime contractor in both irrigation experiments and one of three steam IPH demonstrations. They have successfully contracted for a major system integration and hardware role in the DOE cost-shared 500 kW small solar power system being built at Almeria, Spain.

A strategy providing the necessary linkage between trough development and commercialization programs will be reflected in the solar thermal multiyear plan, now under revision. The near term focal point of the strategy will be existing applications experiments and their use to validate improved concentrator subsystem designs. Over the longer term, additional application experiments will provide an opportunity for potential system suppliers to demonstrate and carefully evaluate "packaged" solar steam supply systems in user environments.

Hemispherical Bowl Technology. The most novel concept under development in the DOE solar thermal program is a quasi-linear concentrating configuration based on a fixed reflecting hemispherical bowl. A moving heat receiver is kept aligned parallel to the direction of incident radiation. Technical activity to date has been conducted under a DOE contract with Texas Tech University for development of prototype hardware to be located at a site near Crosbyton, Texas. The design of a 65-foot diameter concentrator incorporating a high temperature steam receiver module has been completed and fabrication is underway at E-Systems of Dallas, Texas.

This test module is intended to validate the performance projections and design features of bowl concentrators that will comprise a 5 MW solar power plant for the town of Crosbyton. The conceptual design of the system, consists of ten 200-foot diameter modules, as illustrated by the artist's concept in figure 10.

The bowl concept poses an interesting array of technical issues, most of which center on the heat receiver. These issues, including a unique geometry and flux pattern, combined with a receiver designed as a boiler/superheater, create a challenging path for technology development. The French solar program encompasses a similar project incorporating a liquid cooled receiver design, which has been successfully tested at a smaller scale. The bowl approach was one of ten concepts evaluated in the recently completed analyses by SERI and Battelle Pacific Northwest Labs (PNL). These studies were aimed at providing a rigorous comparative evaluation and ranking of solar thermal concentrator concepts for small community electric applications in the 1 to 10 MW size range. The bowl, as represented by the Texas Tech/E-Systems design, was ranked low among the ten concepts by SERI, however an adaptation of the design employing a liquid cooled receiver was ranked considerably higher by PNL. These results raise serious questions regarding the bowl's competitive potential for small community electric applications.

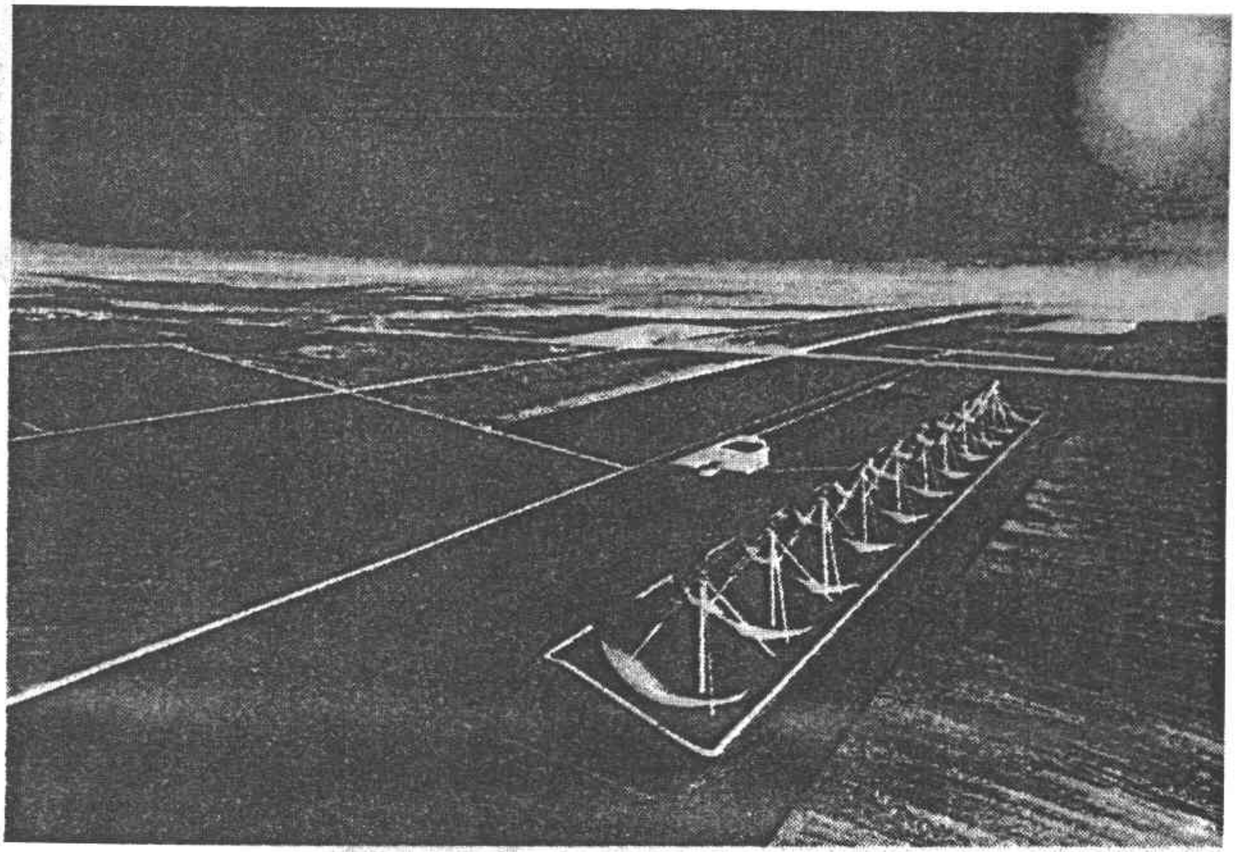

Figure 10. 5 mW Hemispherical Bowl Pilot Plant (Artist's Concept); Crosbyton, TX

However, recent Texas Tech/E-Systems cost estimates for the 5 MW Crosbyton pilot plant place the cost of this first of a kind system at $25M. This suggests that bowl systems can be built today at a factor of four times the cost established by program goals. The cost/value gap is roughly the same magnitude as for other concentrator concepts. Learning curve effects for bowls are somewhat more speculative than for other concepts involving more off-site fabrication. Nevertheless, construction of the 5 MW system as a demonstration will be warranted, if the present cost estimate holds firm and performance and reliability predictions are validated for the 65-foot module. In anticipation of a successful outcome, preliminary design of the 5 MW system will be initiated later this year and is scheduled to be completed in parallel with the first phase of the 65-foot module test program. Although there is some question as to the bowl's competitive prospects in electric applications, between 1 and 10 MW, other sizes and applications may prove to be equally attractive. The intrinsic modularity of the concept appears to be less than 1 MW, but both smaller modules and arrays of larger modules should be possible without serious deterioration in cost effectiveness. For applications larger than 10 MW, however, central receivers are expected to be highly competitive. Smaller applications for bowls, such as irrigation pumping, have yet to be carefully evaluated. They may prove attractive based on the potential size match between an optimized single bowl and a typical pumping installation.

In view of the need to more carefully assess the potential market for bowls, Sandia Laboratories at Albuquerque has been assigned the task of preparing a bowl technology development program plan. This plan will assure appropriate cross fertilization between bowl development activities and those related to other concentrator concepts.

The present industrial base for commercialization of bowl technology is perceived to be even narrower than that for other linear systems.

Texas Tech University is the primary developer of the concept, and only one U.S. company, E-Systems, of Dallas, Texas is involved in its development. This is a key issue to be addressed by the bowl technology plan.

Parabolic Dishes

Parabolic dishes and other point focusing distributed receiver concepts provide a technical path for the program which offers the highest possible optical performance, high temperature capability, minimum land use, as well as a high degree of modularity. Land use advantages increase with latitude, as other concepts suffer more from "cosine losses."

Dish systems are also potentially the most versatile concentrator approach relative to the array of possible markets for solar thermal systems, not only from the point of view of geography, but temperature capability and system size as well. Heat can be produced over a wider temperature range than in the case of troughs and bowls, which have lower feasible concentration ratios. Dish systems for heat and electricity can be as small as tens of kw, i.e. below the likely minimum economical size for small central receivers. The maximum economical size of thermally connected dish systems is generally less than that of central receivers, and decreases sharply as the temperature of delivered heat increases. Nevertheless, concepts under development for electrically and thermochemically connected dish arrays (for electric power and industrial heat) would substantially increase economically allowable system size, to a point where dishes will present an option for bulk energy supply. Electrically connected systems can integrate small heat engines with dish receiver modules, generating electricity at each module ratio rather than at a central point.

Dish thermal concentrators have substantial land use and potential cost/performance advantages (based on high optical, thermodynamic and hence overall conversion efficiency). They also mate well with energy storage concepts which are less costly than currently available or advanced batteries. The integration of fossil fueled combustors or boilers for hybrid operation combines possible higher capacity factor operation, high reliability, and availability with minimal effect on energy cost. The creation of cascaded, mixed heat, and electric production systems (thus greatly enhancing collector utilization efficiency) adds further to potential advantages in residential and commercial applications.

Both intermediate-temperature (less than 1000° F) and high-temperature dish system concepts are under development. A mid-temperature parabolic dish system experiment at Shenandoah, Georgia (figure 11) will begin operation in 1981. An array of 750° F dish concentrators serves the electric, heating and cooling, and low temperature steam needs of a knitwear plant. Peak electric output will be 400 kW. Project component development is complete and prototypes (figure 12) of the dish design are undergoing validation tests at the MSSTF.

A higher temperature thermally connected system (also under development by General Electric) is under consideration for a 1 MW Small Community Experiment, for which a site solicitation is nearly ready. The competing concept is an electrically connected array of engine coupled dish modules under development by Ford-Aerospace. Selection between these two will be made at the completion of the preliminary design phase in late FY 1979. Industry and utility response to both the Shenandoah and Small Community projects has been enthusiastic.

Meanwhile, component development efforts analogous to those in the trough program are under way under the technical direction of JPL. These include engineering development of first and second generation concentrators and receivers, as well as engine adaptation studies and advanced development of dish modules incorporating Brayton and Stirling engines.

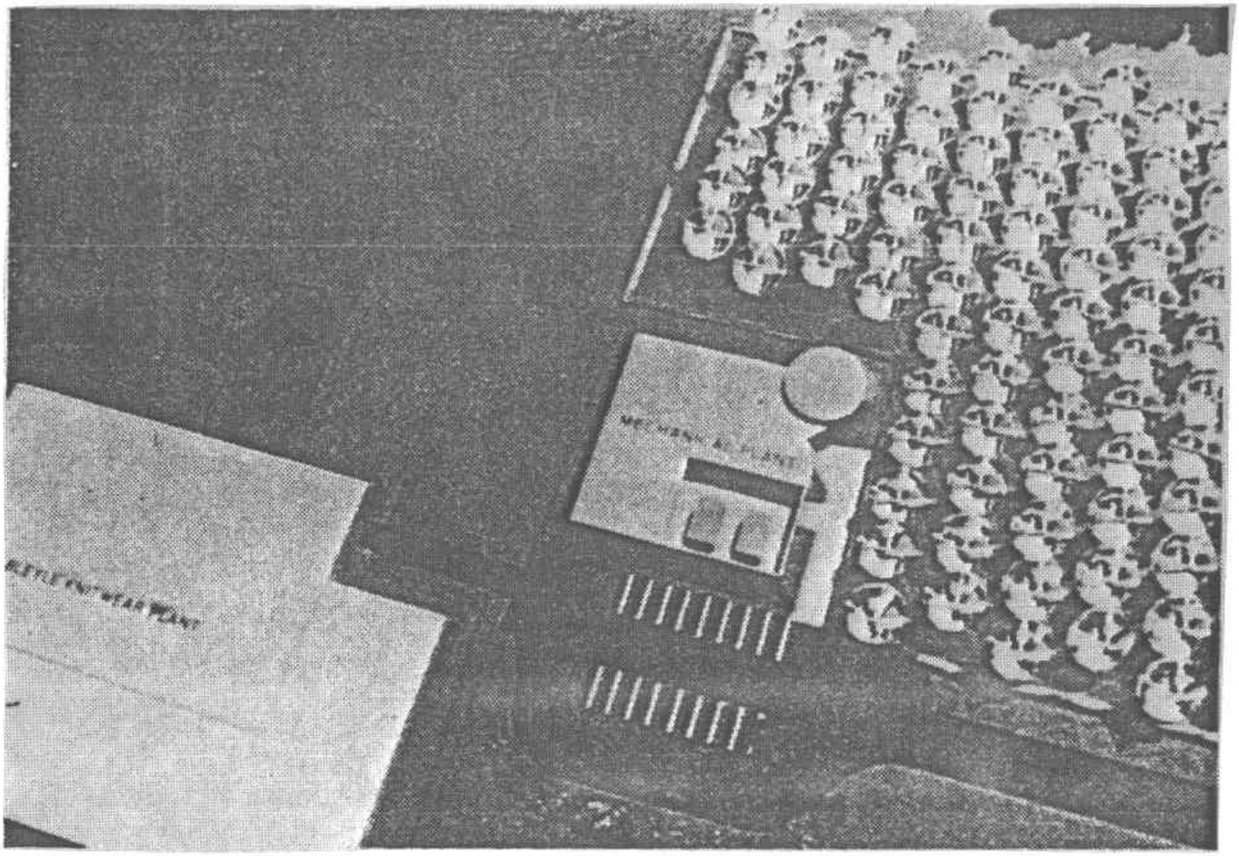

Figure 11. Large Scale Total Energy Experiment (Artist's Concept); Shenandoah, GA

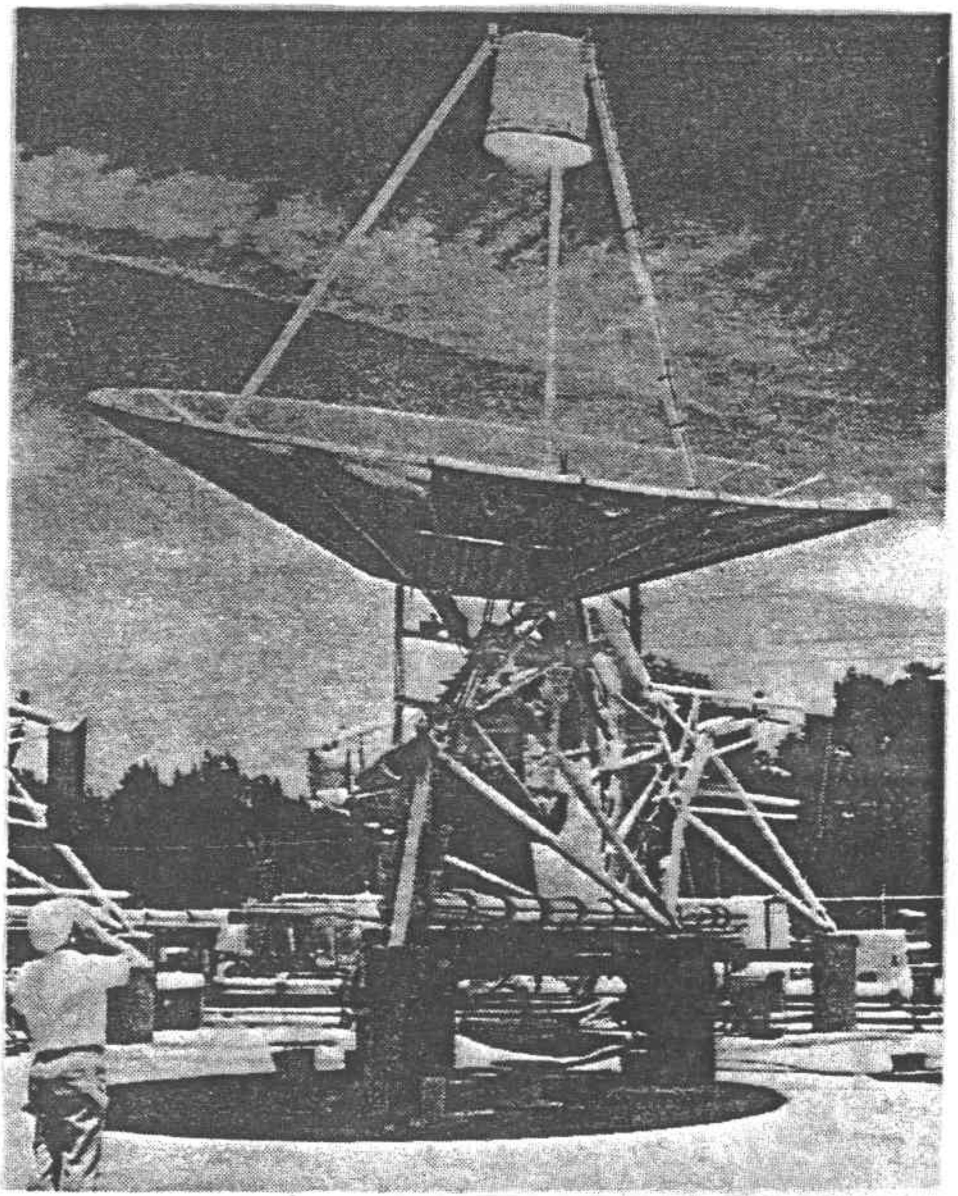

Figure 12. Dish Concentrators for Shenandoah Project at MSSTF

Important decisions regarding strategy will be made in the dish concentrator program. JPL, the technical program manager for dish development, is expected to propose a long-term development strategy which will bring dish technology to the point of meeting technical and cost goals within expected budget constraints. Dish systems have potential in several markets, but this strategy must be based on identification of appropriate early markets. Which of these provides the best opportunities in the near- and long-term? Remote and isolated electric loads is a primary market target for photovoltaics. From a strictly market development point of view, photovoltaic penetration could either enhance or reduce the attractiveness of this market for dish thermal electric systems. Unlike photovoltaic arrays, commercial production and marketing of dish power modules is not yet under way, in spite of pioneering efforts by Omnium-G in this arena. DOE funded dish development had a late start relative to other solar thermal options, causing the present dish industrial base to be weak in terms of manufacturers prepared to supply integrated systems. The advancement of the photovoltaics industry is supported by both products and $150 million per year in Federal funding. The strategic implications of the potential head-to-head competition between dish thermal electric and photovoltaic systems need to be addressed. The issue involves funding needs and priorities as well as coordinating technology development and commercialization efforts to enhance the implementation of both options.

There are other strategic issues. At least four distinct engine concepts are suitable for engined coupled dish modules. Each case requires different storage and/or fossil back-up technology, involving a wide range in technical difficulty and development cost.

Concepts having greatest promise on a cost/performance basis will likely be the most expensive to develop. Because of this an assessment of development mortgages for government and industry is critically needed.

Once intermediate temperature concepts have been introduced commercially, another major development strategy question is whether to assume a natural extension of dish temperature capability upward via industry R&D. Alternatively, all present R&D attention could be focused on high temperature concepts that incorporate Stirling and Brayton engines. The issue hinges on R&D costs, available budgets, and the availability of attractive markets for utilizing dish systems in higher temperature applications. The availability of these attractive markets in turn depends on the competition, which may be photovoltaics or other thermal concentrator concepts. While advantages can be claimed for dish based systems in many market sectors, these advantages need to be better quantified. An assessment of the potential for thermally connected dish systems to compete with central receivers, troughs and bowls in the IPH market is particularly needed. Competition from troughs in applications up to 600° F and from small central receivers in applications above 600° F is expected to be stiff. Quantitative assessment of the potential cost/performance superiority of dish thermal electric systems over photovoltaic systems is also needed.

ADVANCED TECHNOLOGY

The advanced technology program, initiated in late 1977, provides a focus for research and development paths which cut across all concentrator system concepts. These include optical and thermal materials, thermal energy storage, environmental studies, support of insolation data collection and model development, and technical information dissemination. Advanced receiver designs are under development which could apply to central receivers or dish concentrators. Speculative, but nevertheless promising, exploratory thermal energy transport and heat engine studies are also under way. Budgets for the advanced technology program element area have grown more rapidly than for any other, doubling in two years to a level of nearly $25 million per year.

The primary strategic thrust of this element is to support development that will, if successful, expand the market potential for solar thermal technology once an industry is established. The attack is proceeding on two major fronts: (1) broadening the range of potential applications to higher temperature IPH and thermochemical fuel production and (2) increasing the energy displacement potential of concentrator systems in major near-term applications. A complementary thrust is to accelerate industrialization by providing a technology base for product improvement. Higher temperature, higher performance thermal subsystem development, as opposed to engineering development of concentrators, allows more effective use of concentrator area.

Storage

Thermal storage system engineering development has significant leverage in expanding the market potential for solar thermal systems. Without storage, all direct solar conversion systems are limited in capacity factor to 20 percent or less in most of the U.S. Short-term electric energy storage is expensive. Economical long-term bulk electric energy storage is not yet on the horizon. The ability to store high temperature solar heat on at least a daily cycle for delivery to IPH load centers or heat engines can increase potential solar capacity factors and related fuel savings by as much as a factor of three. Storage can be instrumental in reducing fossil fuel consumption where hybrid operation with fossil sources is necessary for system reliability. Storage can also serve to buffer the effects of load and insolation transients on solar heat source equipment and thermal conversion systems, respectively.

For these reasons, support of engineering development of storage concepts compatible with first and second generation concentrator systems has a high priority within the advanced technology program. A multiyear program plan for thermal storage technology development in support of solar thermal programs will be issued later this year. A draft of this plan was recently made available for public comment. The DOE Division of Energy Storage will manage the effort with a budget of roughly five million dollars per year beginning in FY 1980.

Fuels Production

The availability of higher temperature receiver and thermal systems will serve to expand market potential in the industrial process heat sector. Perhaps even more significant in the long term, the high temperature capability under development may allow solar to be adapted to efficient thermochemical processes for production of synthetic transportable fuels from renewable materials. Steps on this path may include conversion of nonrenewable but abundant materials such as coal and organic residues.

Significant developments in high temperature receiver technology have already been made. A 250 kW_t receiver developed by Sanders Associates has been successfully tested to 2000° F at the DOE Advanced Components Test Facility (ACTF) at the Georgia Institute of Technology (see figure 13). Designs having potential capability above 2500° F have been selected for development. Recent tests at White Sands have indicated the feasibility of coal gasification processes and oil shale retorting using a high-temperature solar heat source.

Supporting Programs

The advanced technology program also provides a focal point and administrative umbrella for coordination and funding of solar insolation and environmental projects and programs. An environmental development plan has been prepared for solar thermal power systems.

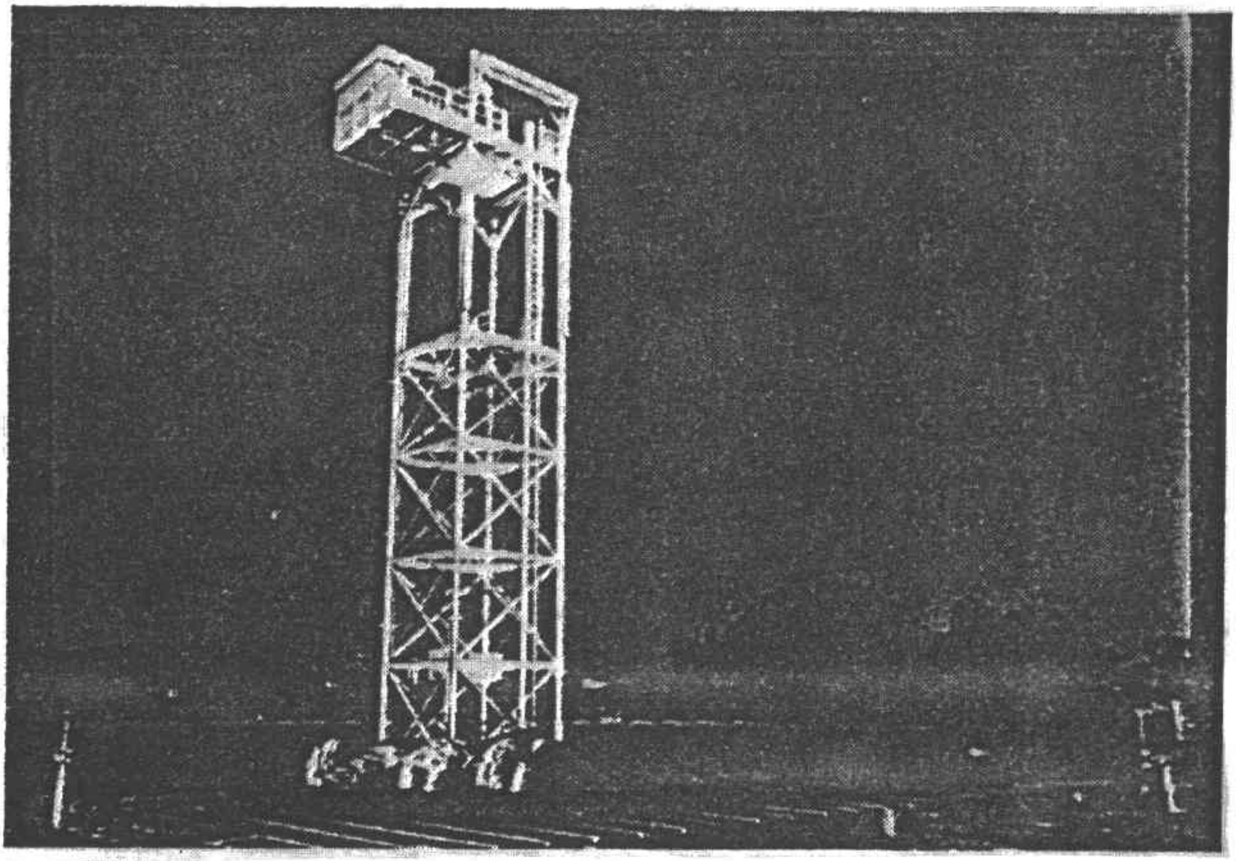

Figure 13. Ceramic Receiver Test, ACTF; Atlanta, GA

Studies funded under this plan are being coordinated by UCLA. The solar thermal budget provides partial funding support for the national solar insolation data base. Depth versus breadth of coverage in the national solar radiation data collection effort is a major issue. The value of the present effort to solar program objectives will be reviewed during the coming year.

New Ideas

Recent initiatives to bring new ideas and new participants into the program are beginning to bear fruit. The Solar Thermal Test Facility User's Association (STTFUA), organized in 1977, serves as a framework within which experimental use of test facility capability, beyond that originally envisioned, is encouraged and recommended. The Association, funded within the Advanced Technology program, solicits, screens, and funds the preparation of experiments. Assistance is also provided in matching experiment requirements with facility capabilities. The STTFUA has attracted a large number of individual, industrial, and university members. More than 30 proposals for use of the CRTF, ACTF, and Solar Furnace at the White Sands Missile Range were received in response to a recent STTFUA solicitation.

Individual faculty members have already made an invaluable contribution in terms of leadership and critical judgment and an expansion of university participation is sought. Future objectives include more effective use of the unique research capabilities available across the whole university community and the fostering of activities that will enable schools and universities to respond to technical and engineering education needs during the program's commercialization phase. As an initial step in this direction, summer faculty research fellowship programs will be offered at major program technical centers during 1980.

The program needs teamwork and discipline in major engineering undertakings. It also needs innovation. Because the small business community thrives on and fosters new ideas for products, small and minority business participation is being actively encouraged. A recent solicitation designed to tap this resource drew over 45 proposals.

Technology Transfer

Effective dissemination of price and product technical information becomes increasingly important as major concentrator concepts approach commercialization. Recognizing this, the program has established a Technical Information Dissemination (TID) office at SERI under the direction of Ms. Margaret Cotton. This office serves as an information outlet for the program, and works closely with the Solar Thermal Energy Association (STEA) Division of the Solar Energy Industries Association (SEIA) to augment industry information resources. The SERI TID office will maintain a current collection of technical reports, and provide an index/abstract service. Documents available will include topical reports on areas of R&D interest, annual technical progress reports, multiyear program plans, and a guide to upcoming solicitations, research opportunities, and meetings. Newsletters covering test facility activities and coming events will also be issued through the TID office.

ACTIVITIES IN OTHER COUNTRIES

Overseas solar thermal activities have three important dimensions: (1) potential markets for U.S. products, (2) potential competition for U.S. industry in these markets, and (3) government supported programs in other countries that have similar objectives to the U.S. program. Reports on overseas solar thermal activities are available (Solar Age, July, 1979).

In general, other industrialized countries lag behind the U.S. in technology readiness, but lead U.S. industry in market development. Several pilot plants are under way in European and Japanese programs. French and German companies are already seeking market opportunities in other countries, with active support from their governments. Overseas visitors and requests for technical advice and information from U.S. program management centers are numerous.

Joint projects with foreign governments are supported within the solar thermal program budget. The Small Solar Power Systems Project conducted under the auspices of the International Energy Agency is an example. Two 500 kW solar thermal electric power systems have been designed and are scheduled for side-by-side construction and operation at a site in Spain, later this year. One incorporates parabolic trough technology, the other a sodium cooled central receiver. The U.S. share of project cost, about eight million dollars, is roughly 20 percent of the total.

U.S. and French scientists are engaged in an ongoing cooperative effort related to reflected radiation, eye damage hazards, convective losses, and other technical issues of mutual interest. U.S. and French high temperature test facility operators are also working together through respective user groups.

The flow of information between U.S. and foreign programs has resulted in a drain on the U.S. energy technology base. This is, in large part, due to the R&D, as opposed to marketable energy systems, orientation of U.S. solar industry. Foreign efforts have centered on the development of systems to meet near-term applications needs. American companies have not been compensated with overseas marketing opportunities largely due to a lack of packaged energy systems. Efforts are under way to minimize the impact of this unfavorable situation. SEIA/STEA recommendations regarding DOE's role in supporting marketing efforts overseas will be given careful consideration.

CONCLUSIONS

Solar high temperature concentrator systems have broad market potential and adapt well to existing industrial facilities and power plants. Feasibility has been established and systems will be ready for commercialization by the early 1980's. Industrial process heat comprises a major near-term market which requires solar/fossil hybrid systems. Screening of this market to identify favorable applications is a high priority task for SERI.

Central receiver technology is well developed. The 10 MW pilot plant near Barstow, California is on track, despite its mixed reception outside the program. Follow-up projects establishing the connection between pilot plant and initial utility and industrial retrofit markets are underway. These projects have received enthusiastic support from the utility industry and potential commercial heliostat suppliers.

In the distributed receiver area, the nucleus of a trough collector industry has emerged. Five companies are in business, others are considering production, and the market is encouraging, given present levels of production. The 65-foot test module, now under construction at Crosbyton, Texas, represents a major engineering hurdle for hemispherical bowl technology. Parabolic dish technology is developing rapidly after a late start. The first major installation involving dishes will be located at Shenandoah, Georgia. Troughs and central receivers afford dish technology a unique market opportunity and thereby present a strong challenge to photovoltaics in remote electric markets, both domestic and international.

Advanced development efforts have the objectives of:

- expanding and accelerating market penetration by improving materials and component performance,

- providing storage technology that enhances capacity factor and fuel displacement potential, and
- providing higher temperature technology for additional IPH applications and, ultimately, for production of transportable fuels by thermochemocal processes.

As mass producible designs are defined and tested and production studies completed, earlier favorable cost projections are holding firm and gaining credibility. Pilot plants designs, if built today, would cost four times the program goals. Improved designs, high volume concentrator production, and experience will fill the gap. Experience is also the key to investment decisions that will initiate commercialization. Experience with real applications beyond initial pilot plants will be necessary to establish user confidence relative to reliability and durability and supplier confidence relative to pricing.

If the present plan is successfully implemented, the DOE technology program faces the brightest of all possible futures; it will put itself out of business.

Experience From IPH Field Tests

REVIEW OF FOUR DOE-SPONSORED SOLAR DEHYDRATION SYSTEMS

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ABSTRACT

The operating experience to date is summarized for four DOE-sponsored solar dehydration systems. These are: a raisin-drying plant in Fresno, CA, a lumber-drying facility in Canton, MS, a soybean-drying plant in Decatur, AL, and an onion-drying plant in Gilroy, CA.

INTRODUCTION

These four solar IPH systems, completely funded by DOE as field experiments, represent first-of-a-kind installations. There has been almost no previous experience with large area industrial solar systems. Consequently it is not surprising that a number of unforseen problems have surfaced in the construction and operation of these systems. The Phase III operations phase of 15 months duration has been completed for three of these projects and is just getting underway for the fourth. The Solar Energy Research Institute is now preparing a comprehensive report summarizing the operating experience for these hot-air systems as well as three hot-water systems also sponsored by DOE.

SOME GENERAL CONCLUSIONS

Before presenting performance and cost data on each of the four projects, it is appropriate to list below some pertinent observations that have resulted from a recent site visit to each plant and discussion with plant personnel and the solar system contractor project manager.

1) The average system efficiency of these solar systems is lower than had been predicted in the Phase I studies. Measured efficiencies are in the range of 30 to 35% whereas predicted efficiencies were in the range of 40 to 50%. Some reasons: dirty glazings, insufficient insulation, wet insulation, not operating in an optimized mode, idealized computer programs.

2) The collector fluid is water in two of these systems and air in the other two. Parasitic electric losses are low for the first two (1% and 1.3%) and high for the second two (11% and 9%). The large volume insulated ducting required for air-heating systems and the large parasitic losses (~30% when expressed in primary fuel required to produce electricity) will limit their applicability, particularly for larger-area IPH systems.

3) Dirt and industrial pollutants are a real problem for each system. All future solar IPH systems (particularly systems using reflectors) should have an automated washing system as part of the original design.

4) It is important to have one or two plant personnel, preferably maintenance engineers, trained in the operation and maintenance of the solar system.

5) Redundant sensors (RTDs, flowmeters, etc.) should be designed into system so that valuable performance data will not be lost due to sensor failure.

6) The data acquisition system and sensors should be completely independent of the control system and sensors.

7) There should be on-site readout of integrated daily solar system heat output so that plant personnel can monitor system performance.

8) CPVC pipe should not be used because of probability of occasional stagnation conditions producing high temperatures and pressures.

9) Waste heat recovery systems (WHRS) generally represent a more attractive investment (shorter payback) than do solar thermal systems. In some cases, the installation of a WHRS will result in making a subsequent investment in a solar system less attractive, i.e., the solar system working fluid is at a higher average temperature because of the inclusion of the WHRS and this results in a lower collector efficiency.

10) The 15 month Phase III period is much too short to obtain long-term performance data on these systems. At least a 3-year period is needed to determine performance, deterioration of components, and operation and maintenance costs.

PROJECT:	L&P Commercial Crop Dehydration Facility, Fresno, CA.
CONTRACTOR:	California Polytechnic State University, San Luis Obispo, CA.
PROJECT MANAGER:	E. J. Carnegie, (805) 546-2814.
Process:	Drying of prunes and raisins.
Collector Area:	20,500 ft^2
Collector Fluid:	Air
Collector Type:	Site-built single-glazed flat-plate.

Average Collector Outlet Temperature: 150 °F

Date of First Operation: Summer, 1978.

Phase I cost:	269K
Phase II cost:	545K
Phase III cost:	154K
Total DOE cost:	968K

SYSTEM DESCRIPTION: Site-built, single-glazed air heaters feed hot air directly to a dehydration tunnel or to a 14,000 ft^3 rock bed storage. Large diameter air ducting collectors to storage and dehydrator. Heat recovery wheel recovers about 80% of exhaust heat from tunnel and furnishes input air to collectors. DAS is an Autodata 9.

OPERATIONAL EXPERIENCE TO DATE: System is working well, furnishing about 75% of heat required by one tunnel. Parasitic electric energy (blower fans to circulate air through collectors, ducting, and storage) is about 11% of collected solar energy. Heat recovery wheel contributes about twice the energy as does solar collector system.

POSITIVE SYSTEM FEATURES: Low-cost site-built collectors work well. Dirt on glazings only reduces performance about 5%. Good performance data being obtained.

PROBLEM AREAS: Lexan glazings have cracked in a number of places due to temperature cycling. Solar heat can only be utilized ~200 days per year (but during months of maximum insolation). Parasitic losses are high. Analysis of solar systems performance is complicated by inclusion of heat recovery wheel. It increases the overall system efficiency but decreases collector efficiency from what it would have been in absence of wheel.

PROJECT: La Cour Lumber Kiln, Canton, MS.

CONTRACTOR: Lockheed Huntsville, Huntsville, AL.

PROJECT MANAGER: Paul McCormack (205) 837-1800

Process: Lumber Drying

Collector Area: 2500 ft^2

Collector Fluid: Water

Collector Type: Chamberlain double glazed flat-plate

Average Collector Outlet Temperature: 160 °F

Date of First Operation: June 1978

Phase I cost:	71K
Phase II cost:	286K
Phase III cost:	119K
Total DOE cost:	476K

SYSTEM DESCRIPTION: An array of double-glazed flat-plate water heaters mounted on a simple wooden frame and with augmentation from Al sheet reflectors. Heated water is stored in a 5000 gallon tank. Water from tank goes to bank of fin-pipe heat exchangers in each of two kilns.

OPERATING EXPERIENCE TO DATE: System has been very reliable and furnished about 15% of annual heat requirements of kilns. (Design figure was 22%.) All PVC pipe had to be replaced with Cu pipe after a stagnation over pressure which burst PVC pipe. PDP-11 DAS has performed well and given real time on-site data.

POSITIVE SYSTEM FEATURES: Collectors look good after 1-1/2 years with exception of two collectors with leaks in absorber plates. Dirt on glazings does not have much effect on performance although dirt on reflectors reduces their effectiveness. All available heat from solar system is effectively utilized by plant. System drains at night so no freezing problems. Parasitic electric energy equals 1% of solar energy provided.

PROBLEM AREAS: Operator of system does not appear to be using an operation mode which would give maximum system efficiency. DAS system was damaged twice; once by steam from broken PVC pipe and secondly by a flooded instrument room.

PROJECT: Goldkist Soybean Dryer, Decatur, AL.

CONTRACTOR: Teledyne Brown Engineering, Huntsville, AL.

PROJECT MANAGER: William Hall, (205) 766-6730

Collector Area: 13,100 ft^2

Collector Fluid: Air

Collector Type: Solaron single-glazed flat-plate

Average Collector Outlet Temperature: 160°F

Date of First Operation: July, 1978.

Phase I cost:	291K
Phase II cost:	823K
Phase III cost:	126K
Total DOE cost:	1240K

SYSTEM DESCRIPTION: An array of flat-plate air heaters mounted on a very large structural steel framework. Preheated air is fed, via a 4' square insulated duct, to the three soybean dryer combustion heater air intakes. The DAS is a Fluke Model 2240A data logger and 12 transducers.

OPERATING EXPERIENCE TO DATE: The system has operated well and reliable performance data have been obtained over the 15 mo. Phase III period. Plant went on a daytime maintenance schedule, drying at night, so only about 54% of available solar heat was utilized.

POSITIVE SYSTEM FEATURES: Collectors have stood up well, air systems have no problems with water leaks and freezing, DAS works well. Open-loop system with no storage so parasitic energy loss held to 9% of collected energy.

PROBLEM AREAS: Severe problem with sticky soybean gum covering collectors. Only solution is a daily washing. Ducting insulation has gotten wet. System efficiency only about half of that predicted by computer program. Only able to utilize about 50% of solar heat due to daytime maintenance schedule.

PROJECT: Gilroy Foods, Inc., Gilroy, CA.

CONTRACTOR: Trident Engineering Assoc., Inc. Annapolis, MD.

PROJECT MANAGER: Payson Sierer, (301) 267-8128

Process: Onion and Garlic drying

Collector Area: 5950 ft^2

Collector Fluid: Water

Collector Type: GE TC-100 evacuated tube

Average Collector Outlet Temperature: 190°F

Date of First Operation: August, 1979.

Phase I cost: 226K
Phase II cost: 618K
Phase III cost: 178K
Total DOE cost: 1022K

SYSTEM DESCRIPTION: An array of TC-100 evacuated tube collectors, mounted on a warehouse roof, supplies hot water to a heat exchanger mounted in the incoming air stream to the first stage of a continuous-belt onion dehydrator. There is no storage. When solar hot water is not used for onion drying it is used to preheat boiler condensate.

OPERATIONAL EXPERIENCE TO DATE: System is operating well, at an average efficiency of about 33% (compared to predicted efficiency of 43%). Automatic washing system is installed and is very effective. Auto Data 9 DAS works well.

POSITIVE SYSTEM FEATURES: Available solar heat can be utilized all year. Simple, low-cost, 2x4 wood support structure. Trained plant engineer has responsibility to closely monitor system performance. Parasitic losses are low ($\sim$1.3% electrical).

PROBLEM AREAS: Wooden frame should have been built with 2x6's to prevent warping and sagging. Heat exchanger tends to clog with onion dust and will need periodic cleaning.

QUESTIONS

Question: Do the GE TC-100 modules used in the hot air installation leak moisture into the insulation as did the units in the hot water application at La France, South Carolina?

Answer: The units have not been in service long enough to make a determination.

Question: Many problems are technical or mechanical ones which could be and probably will be resolved with the development of the technology, especially once these are experiments and not demonstrations. Were there problems that were related to the system design and its integration with process? Appropriateness or compatibility, etc.

Answer: There have been a number of problems involving poor system design. For example, in one of the hot water systems, ambient water is first heated by flat plate collectors, then further heated by parabolic troughs, then stored in a large storage tank. No provision was made for recirculating this stored water back through the collectors if it was still not very hot due to poor weather. Also, we are learning from these field experiments about the "do's and don'ts" of integrating the solar system with the already existing conventional system.

Question: Where do the parasitic losses occur in the air collection system? In collectors or distribution system?

Answer: On a daily basis about 50% of the parasitic loss comes from pushing air through the rock bed storage and the heat recovery wheel. The other 50% comes from pushing air through the collector.

Question: In an air system like the fruit drying operation, most of the parasitic energy is for operation of the fan, and is converted to heat in the moving air. In the energy accounting procedure, therefore, shouldn't this energy be subtracted from the parasitic losses and also substracted from the solar heat gain?

Answer: About 80% of the parasitic electric energy is converted to useful heat in the air stream. This represents only about 7 to 8% of the heat supplied by the solar system. The simplest way to handle this is to charge the parasistic electric energy as an operating cost (which it is) and let the solar system take credit for the 7 to 8% additional heat provided.

REVIEW OF FOUR DOE-SPONSORED LOW TEMPERATURE STEAM SYSTEMS

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ABSTRACT

This paper describes the system characteristics and limited operating experience of four DOE-sponsored low temperature steam system field tests. The WestPoint Peperell (Honeywell) installation in Fairfax, Alabama, has been operational for nine months but has experienced numerous minor equipment and system problems and a major problem with its shadow bar tracker. The other three installations are not operational yet. Johnson and Johnson (Acurex) in Sherman, Texas, is currently in the startup and checkout phase and will be operational in December, 1979. Home Laundry (Jacobs-Del) in Pasadena, California, and Tropicana Products (General Electric) in Bradenton, Florida, are both well into the construction phase and expect to be operational in February, 1980.

INTRODUCTION

These four low temperature steam IPH systems are the first ones to be built. It is, therefore, not surprising that many problems have arisen, even with only one system actually in operation. The major discovery made is that the shadow bar type tracker does not seem to work effectively in the southeastern U.S., whereas it has successfully functioned in other parts of the country. All other problems encountered to date have been relatively minor, but they have had some impact on system cost and performance. Three collector types are continuously tracking parabolic troughs. The fourth is a low concentration ratio, seasonally adjusted collector. Since the latter is located in a southeastern region where the direct insolation is only 85% of the total, it will be interesting to compare its yearly collected energy with one of the high concentration ratio troughs also located in the southeast.

None of the four field tests seems to be a good indicator of eventual system costs for several reasons. First, all systems are small by industrial standards and, also, by the portion of total plant IPH which they supply. Second, there have been many improvements and refinements made to the collectors during Phases I and II which were charged to the total system costs. Third, and most important, these are the initial IPH steam systems, so, each contractor is at the very beginning of the learning curve. However, these projects can be instructive in pointing to the parts of the system that require substantial cost reduction efforts.

Characteristics of the four low temperature steam systems are detailed on the following four pages.

PROJECT:	Home Laundry Co., Pasadena, California
CONTRACTOR:	Jacobs-Del Solar Systems, Inc. Pasadena, California
PROJECT MANAGER:	Bernie Eldridge (213) 449-2171
PROCESS:	Supplying process steam for laundry processing and finishing
COLLECTOR AREA:	604 square meters (6496 square feet)
COLLECTOR TYPE:	DEL parabolic trough, mounted north-south, continuous tracking
COLLECTOR FLUID:	Pressurized water
COLLECTOR OUTLET TEMP:	190 to 210 °C
DATE OF FIRST OPERATION:	February, 1980
PHASE I COST:	$167K
PHASE II COST:	$801K
PHASE III COST:	$55K (12 months)
TOTAL COST:	$1023K
SYSTEM DESCRIPTION:	Pressurized water is circulated through the collector field and through a small buffer storage tank or a heat exchanger in the steam generator tank which normally is at 175 to 205 °C. Steam is supplied to the main plant steam line at 175 °C. System pressure is maintained by a nitrogen blanket and expansion tank system.
OPERATIONAL STATUS:	Construction phase. Structural steel collector platform completed. Collector installation began in October. Boiler room modifications 40% complete.
POSITIVE SYSTEM FEATURES:	Provides one fourth of the plant steam load. Good cooperation from industrial partner, city, and gas and electric company. Very visible location in a large metropolitan area.
PROBLEM AREAS:	Delays due to tax questions plus a steel fabricator strike increased Phase II cost. Necessity for a complete structural steel collector support from ground to over roof level significantly increased Phase II cost. No ground area or expansion area is available.

PROJECT: Johnson and Johnson, Sherman, Texas

CONTRACTOR: Acurex Alternate Energy Division, Mountain View, California

PROJECT MANAGER: Stan Youngblood (415) 964-3200, x-3530

PROCESS: Supplying process steam for plant use in manufacturing cotton gauze products

COLLECTOR AREA: 1070 square meters (11520 square feet)

COLLECTOR TYPE: Acurex Model 3001 parabolic trough, mounted northeast-southwest, continuous tracking

COLLECTOR FLUID: Pressurized water

COLLECTOR OUTLET TEMP: 215 °C maximum

DATE OF FIRST OPERATION: December, 1979

PHASE I COST: $214K

PHASE II COST: $1613K

PHASE III COST: $200K (15 months)

TOTAL COST: $2027K

SYSTEM DESCRIPTION: Pressurized water is circulated through the collector field and is then throttled into a flash boiler. The 183 °C water in the boiler flashes to steam to supply the main steam line at 174 °C.

OPERATIONAL STATUS: Startup and checkout phase. Construction began in April, 1979, and was completed in September, 1979.

POSITIVE SYSTEM FEATURES: Conveniently located ground mounted collectors with simple interface to existing plant. Additional land available for collector field expansion. Energy utilization every day as collected. Enthusiastic, involved industrial partner.

PROBLEM AREAS: Additional engineering design work plus many aesthetic constraints resulted in high Phase II costs. Allowing more space for boiler room area would have made piping installation easier. Minimum spacing between collector rows should be about 6 meters for construction convenience.

PROJECT: Tropicana Products, Inc., Bradenton, Florida

CONTRACTOR: General Electric Space Systems Organization, Valley Forge, Pennsylvania

PROJECT MANAGER: Jim Trice (215) 962-1150

PROCESS: Supplying process steam for the Nation's largest citrus juice plant

COLLECTOR AREA: 929 square meters (10000 square feet)

COLLECTOR TYPE: G.E. TC-300 with evacuated tubes, 2.9x concentration, nontracking, seasonally adjusted

COLLECTOR FLUID: Pressurized water

COLLECTOR OUTLET TEMP: 150 °C

DATE OF FIRST OPERATION: February, 1980

PHASE I COST: $235K

PHASE II COST: $1075K

PHASE III COST: $250K (15 months)

TOTAL COST: $1560K

SYSTEM DESCRIPTION: Pressurized water is circulated through the collector field and through a heat exchanger in the steam generator tank which normally is 150 °C. The steam from the upper portion of the generator is supplied to the main steam line at 125 °C.

OPERATIONAL STATUS: Construction phase. Site work is 80% complete. Collector performance testing is complete. Collector production is 15% complete.

POSITIVE SYSTEM FEATURES: Nontracking, low concentration ratio collector which will collect over one-third of the diffuse energy. Simple ground mounting of collectors. Process interface is at a relatively low temperature (125 °C).

PROBLEM AREAS: Collector field location had to be moved from roof to ground due to structural problems and higher cost. New location has a 500 meter long pipe run from field to application. Some collector efficiency tests indicate poor performance.

PROJECT:	WestPoint Pepperell, Fairfax, Alabama
CONTRACTOR:	Honeywell Inc., Minneapolis, Minnesota
PROJECT MANAGER:	Paul Mitchell (612) 378-5431
PROCESS:	Supplying process steam to textile dryers
COLLECTOR AREA:	697 square meters (7500 square feet)
COLLECTOR TYPE:	Honeywell half-parabola trough, mounted southeast-northwest, continuous tracking
COLLECTOR FLUID:	Pressurized water
COLLECTOR OUTLET TEMP:	195 °C
DATE OF FIRST OPERATION:	December, 1978
PHASE I COST:	$146K
PHASE II COST:	$598K
PHASE III COST:	$150K (12 months)
TOTAL COST:	$894K
SYSTEM DESCRIPTION:	Pressurized water is circulated through the collector field and through a heat exchanger in the steam generator which normally is at 193 °C. Steam flows from the generator into the steam line at 160 °C and to the dryers.
OPERATIONAL STATUS:	System operated intermittently from December, 1978, through June, 1979, with an improving reliability trend. System has been down since June, 1979, due to failure of a gear box and the field circulation pump.
POSITIVE SYSTEM FEATURES:	Successful installation on existing roof. Collector field close to solarized drying process. Relatively low Phase II cost per unit collector area.
PROBLEM AREAS:	Shadow bar tracker does not work well under southeastern insolation conditions and will have to be replaced by a new flux line tracker. System developed leaks due to pipe expansion problem and freeze problem. Field circulation pump had wrong voltage rating and failed in six months. One gear box failed.

QUESTIONS

Question: Costs of systems?

Answer: Range \$80 - 140/ft^{2}
(Phase 2 cost/ft^{2})
includes project management costs and special engineering design-
does not include Phase 1 design costs

THE SEVEN DOE INTERMEDIATE TEMPERATURE (350°F - 550°F) STEAM DEMONSTRATION PROJECTS

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ABSTRACT

This review paper provides a synopsis of the seven Department of Energy (DOE) intermediate temperature (350° - 550°F) steam demonstration projects, the designs of which were completed in June of 1979. These projects were designed by various private contractors to provide a portion of the process steam requirements used in a variety of industrial processes including oil heating, latex production, hectorite processing, oil refining, brewing, chlorine manufacturing and potato processing. For all but one of these projects, two generic kinds of system configuration have been utilized: 1) pressurized water is circulated through a collector field and then flashed to steam in a low pressure chamber, or 2) an organic heat transfer fluid is circulated in the collector array and then fed to a steam generator where the fluid serves as a heat source to produce steam. The system design of each of these seven projects is outlined in this review and the current status of each project is cataloged. Finally, the objectives of this current series of DOE demonstration projects are discussed, and the potential impact of programs such as these upon the widespread commercialization of solar energy process heat applications within the private industrial sector of the United States is addressed.

INTRODUCTION

DOE conducts a federally funded demonstration program designed to facilitate the rapid and widespread commercialization of solar energy within the private industrial process heat sector. Specific goals of this program include:

- The design and testing of solar industrial process heat (IPH) systems together with the identification of problems and barriers to commercialization;
- The encouragement of systems development in order to insure efficient and cost-effective solar applications;
- The identification, recommendation, and adoption of investment incentive programs by the Federal Government; and
- The assessment of the potential for application of solar energy to industrial process heat applications and the identification of appropriate processes and locations where solar energy can significantly satisfy process energy requirements.

Also included in the mission of the DOE Solar IPH Program are the identification and public expression of the advantages of industrial applications of solar energy. These advantages include the alternative that solar offers to increasingly expensive conventional fossil fuels together with the reduction of environmental degradation and the achievement of needed conservation of renewable resources, both of which can be achieved by the utilization of solar energy.

By the end of FY-1978, the Department of Energy had funded various phases of design, construction and testing of 18 experimental projects providing hot water, hot air and steam for industry. Seven of these projects are for the production of intermediate temperature (350° - 550°F) steam. A description of these seven projects, including the objectives and current status of each, is the subject of this review paper.

THE SEVEN INTERMEDIATE TEMPERATURE PROJECTS

1. ERGON, Inc. (Mobile, Alabama)

This system was designed by Acurex Corporation to provide solar process heat to the ERGON, Inc., Mobile, Alabama Bulk Terminal. At this terminal, petroleum oils in bulk storage are heated daily to lower the viscosity of the oils, thus making them easier to pump. Currently, a conventional fossil fuel heater furnishes the required process heat.

Acurex Corporation completed the design phase of this proposed project in June 1979. In this design, a heat transfer fluid (Therminol 55) capable of high temperature operation is circulated through a ground mounted collector field. The sensible heat of this fluid is then utilized for the process requirements. It should be stressed that an important feature of all of seven designs is the compatibility of the proposed solar process applications with the existing systems. The ERGON solar energy addition is designed to provide heat to the process through the existing oil storage tank heat exchangers, using the same heat transfer fluid as the fossil-fuel heater. A summary of the proposed ERGON solar energy system is presented in Table 1 below.

Table 1. ERGON SYSTEM SUMMARY

Configuration: Organic heat transfer fluid/heat exchanger

Collectors: Line focusing parabolic troughs (20,160 ft^2)

Process Requirements: Therminol-55 heated to maximum temperature of 258°C(496°F)

Acurex designed the ERGON system to supply approximately 55 percent of the process heat required by the No. 6 oil at the ERGON, Inc.

Mobile facility. The proposed system would supply about 2.7 billion KJ (2.6 billion Btu's) per year; this is equivalent to about 653 barrels of oil or 2.4 million standard cubic feet of natural gas. Although the design of this system has been completed, a construction schedule is uncertain at this time.

2. Dow Chemical (Dalton, Georgia)

The proposed solar energy process steam application designed by Foster Wheeler Development Corporation for the Dalton, Georgia Dow Chemical facility is scheduled for completion by October of 1980. The Dalton plant is the world's largest producer of styrene butadiene rubber latex (SBR); about 20 percent of the total latex demand is supplied from this facility.

In 1978, steam production at Dow's Dalton facility consumed 103 billion Btu's of energy from fuel oil and natural gas, with 75 percent obtained from natural gas and the remainder from No. 2 fuel oil. Nearly two-thirds of the steam at this facility is required at a pressure of 150 psi or below. The fact that 1500 Btu's are required to produce 1 pound of SBR latex serves to dramatically underscore the energy requirements of the process.

The Foster Wheeler design for the Dow system utilizes a heat transfer loop which delivers a hot, heat transfer fluid (Dowtherm - LF) from the line focusing parabolic trough collectors to a conventional non-fired steam boiler. The heat transfer fluid furnishes the heat required to convert the feedwater from the existing steam plant into saturated steam at 155 psi.

A summary of the proposed Dow solar process steam application is presented in Table 2 below.

Table 2. DOW SYSTEM SUMMARY

Configuration: Organic heat transfer fluid/heat exchanger

Collector: Line focusing parabolic troughs (9930 ft^2)

Process Heat Requirements: Saturated steam at minimum pressure of 155 psi.

Foster Wheeler designed this system to provide 2.63 billion KJ (2.54 billion Btu's) per year for steam production. This represents approximately 37.5 percent of the total steam requirement for the number 2 plant at the Dalton facility at peak solar conditions and about 7.1 percent on an annual basis. This is equivalent to about 2.3 million standard cubic feet of natural gas or 650 barrels of oil. This system is scheduled for completion in October of 1980.

3. National Lead Industries (Newberry Springs, California)

The Industrial Chemical Division of National Lead Industries, Inc., together with Jacobs - Del Solar Systems, Inc. have proposed a solar system to produce a portion of the process steam requirements of the National Lead Industries' (NLI) hectorite ore processing facility in Newberry Springs, California. The solar process steam will be supplied to dryers used for hectorite clay drying.

The proposed solar system, the design of which was completed by Jacobs - Del in June of 1979, will consist of an array of parabolic trough collectors mounted on earth berms at a tilt angle of 7.5 degrees facing south, thus increasing energy collection by reducing end and cosine losses.

The pressurized water system is designed to generate a temperature of 232°C(450°F) in a closed circuit piping system. A pump circulates water from the solar array to a steam generator and back to the array. Freeze protection is accomplished by utilizing waste energy from the boiler economizer or the hot water tank. A summary of this system is presented below.

Table 3. NATIONAL LEAD INDUSTRIES SYSTEM SUMMARY

Configuration: Pressurized water/flash separation

Collectors: Line focusing parabolic troughs (10,240 ft^2)

Process Requirements: 162 psi steam

The NLI system was designed to supply approximately 3.3 billion KJ (3.2 billion Btu's) to the process. This is equivalent to about 796 barrels of oil or 2.9 million standard cubic feet of natural gas. Construction plans for this project are not well-defined at this time.

4. Southern Union Co. (Hobbs, New Mexico)

Monument Solar Corporation completed the design for a system to provide process steam to the Southern Union Company's Famariss Oil Refinery in Hobbs, New Mexico in May of 1979. The solar system will consist of two loops: 1) the primary thermal transport loop where a heat transfer fluid (Texatherm) is circulated through the solar collectors and solar steam generator, and 2) an interfacing loop between the

Famariss Refinery and the solar system. This secondary loop incorporates the feedwater from the refinery's boiler feedwater pumps as well as the steam discharged from the solar system to the refinery's steam header pipe. Feedwater will be supplied at approximately 104°C(220°F) while 175 psi saturated steam at 191°C (375°F) will be provided to the Famariss plant. This two-loop system was chosen in order to insure against the possibility of contaminating the conventional industrial steam process in any way. Table 4, below, provides an outline of important system parameters.

Table 4. SOUTHERN UNION REFINING COMPANY SYSTEM SUMMARY

Configuration: Organic heat transfer fluid/heat exchanger

Collectors: Line focusing parabolic troughs (10,080 ft^2)

Process Requirements: 175 psi steam

The proposed solar system is designed to provide approximately 3.7 billion KJ (3.5 billion Btu's) to the Famariss Refinery in an average year. This will reduce the fuel consumption for the generation of process steam by the equivalent of approximately 4.3 million cubic feet of natural gas or 890 barrels of oil per year. The system is scheduled for completion in October of 1980.

5. Stauffer Chemical Company (Henderson, Nevada)

The proposed solar process steam application at the Stauffer Chemical Company facility in Henderson, Nevada provides another opportunity for the production of solar energy in the chemical industry, an industry which current accounts for approximately 25 percent of the total industrial energy requirement of the United States. Chilton Engineering, together with Pacific Sun, Inc. and the Desert Research Institute, have designed a solar process steam system for the Stauffer chlorine and caustic soda facility in Henderson. The total steam production at this large industrial complex is approximately 155,000 lbu/hr with the bulk of this energy (approximately 70 percent) required by the Stauffer chlorine and caustic plants.

The proposed Stauffer solar process steam system is a pressurized water/flash separation system with steam produced at design conditions of 155 psi and 187°C(368°F). Freeze protection is provided by pump circulation together with an emergency manual drain. One unique feature of this design is the mounting of the steam separation drum twenty feet on a tower, above the receiver tubes. This reduces the horsepower of the circulation pump required to maintain the proper flow rate through the collector array; thus, the parasitic losses attribitable to this pump are minimized. The proposed solar system has been designed to supply approximately 1500 lbm/hr of steam to the Stauffer facility. The following table provides a system summary.

Table 5. STAUFFER SYSTEM SUMMARY

Configuration: Pressurized water/flash separation

Collectors: Line focusing parabolic troughs (10,592 ft^2)

Process Requirements: 155 psi steam, 187°C(368°F)

One major problem encountered at the Stauffer facility is the extremely caustic environment in which the solar system will operate. Initial studies suggest that relatively swift degradation of the collector's reflective surfaces may result. Construction of the Stauffer facility may be delayed pending an economically viable solution to this potential problem.

6. Ore-Ida Co. (Ontario, Oregon)

Ore-Ida Foods, one of the largest national producers of frozen potato products, currently uses two dual-fired boilers (gas or oil) each producing 300 psi steam at the rate of 50,000 lbs per hour. Forty-five percent of this steam is used at 214°C(417°F) for all the potato frying operations. At the Ore-Ida facility in Ontario, Oregon, the total annual steam requirement for frying the potato products amounts to 250 billion Btu's.

TRW Energy Systems has designed a solar process steam system for the Ore-Ida facility consisting of an array of in-line parabolic trough concentrating collectors installed on the roof of the Ontario facility in close proximity to the heat exchanger of the Ore-Ida prime fryer number 2. The annual steam requirement of fryer line number 2 is 48 billion Btu's. The TRW system will utilize pressurized water as the heat transfer fluid. This water circulates through the collector field and then flashes to steam and water. Table 6 provides a summary of major features of the proposed solar system.

Table 6. ORE-IDA SYSTEM SUMMARY

Configuration: Pressurized water/flash separation

Collectors: Line focusing parabolic troughs (9800 ft^2)

Process Requirements: 300 psi steam

The Ore-Ida system will supply approximately 2.81 KJ (2.7 billion Btu's) per year to the process steam requirements of the Ore-Ida Ontario facility. This is equivalent to about 680 barrels of oil or 3.25 million standard cubic feet of natural gas. The system is scheduled for completion in October of 1980.

7. Lone Star Brewery (San Antonio, Texas)

The final design is the Lone Star Brewery in San Antonio, Texas. This brewery has a steam requirement of 125 psi and 178°C(353°F) at the rate of approximately 50,000 lb/hr. Currently, this steam requirement is met by natural gas fired boilers with diesel fuel burners installed for use as a supplement in the event of a natural gas curtailment.

The Southwest Research Institute's design concept for the Lone Star solar system is to circulate a heat transfer fluid (Therminol T-55) through a roof-mounted line focusing parabolic trough array and then pass the heated fluid through the tube bundle of an unfired boiler. The steam produced in the shell of this boiler will then be transported to the process steam header. The table below summarizes the important parameters of the proposed solar system.

Table 7. LONE STAR BREWERY SYSTEM SUMMARY

Configuration:	Organic heat transfer fluid/heat exchanger
Collectors:	Line focusing parabolic trough (9450 ft^2)
Process Requirements:	125 psi steam

The steam requirement for the Lone Star Brewery immediately downstream from where the solar-produced steam will be injected is 6000 lb/hr, seven days per week. The maximum output of the produced solar system will be approximately 1700 lbs/hr, or 3.32 billion KJ (3.2 billion Btu's per year). This represents 28% of the load downstream from the solar process steam injection point and 3% of the total plant load. In terms of fuel savings, the solar system will conserve approximately 882 barrels of oil or 3 million standard cubic feet of natural gas per year. It is interesting to note that the United States brewing industry as a whole has an estimated yearly energy cost of $235 million. Completion of the Lone Star solar energy system is also scheduled for October of 1980.

III. CONCLUSIONS

The seven solar IPH intermediate temperature steam demonstration projects promise to continue to improve the commercial viability of solar energy applications within the industrial sector. Currently, solar systems are technically feasible for providing industrial process steam over a relatively wide range of temperatures; however, early experience in the design phase of the current seven steam projects together with experience obtained from the previous generation of low-temperature (212°-350°F) steam projects suggests that technology research and development efforts are still required in specific areas:

- Reflective materials and coatings, in order to overcome the potential difficulties posed by harsh industrial environments;
- Improved insulation materials, in order to minimize thermal losses and improve the cost-effectiveness of solar applications;
- Collector controls, in order to make systems more efficient and reliable; and
- Materials utilization, in order to insure that the efficiency, dependability and economic attractiveness of solar collectors and their supporting structures, as well as system peripheral components, are maximized.

The seven projects discussed herein will help demonstrate the feasibility of utilizing solar energy to generate industrial process steam at these temperatures and will continue to identify specific areas whereby future solar IPH systems can be improved. A standardized real-time minicomputer based data acquisition and processing system specified by the Solar Energy Research Institute (SERI) will be utilized by each of these seven projects, thus insuring a solid data base with which to analyze, compare, and monitor these systems after their completion. The demonstration of feasibility afforded by these projects, together with the experience and knowledge gained, is a necessary precursor to the projected decrease in systems cost attributable to mass production, improved design and new, more cost-effective materials utilization. All of these factors, together with certain inflation of the costs of more conventional fuels, insure the near-term evolution of dependable, cost-effective solar energy utilization within the industrial sector of the United States.

In conclusion, it should be emphasized that this paper presents only a simple review of the inspired efforts and resulting designs of the contractors and industrial partners associated with each of these projects. Their generous cooperation with the preparation of this overview is gratefully acknowledged.

SOLAR INDUSTRIAL PROCESS HEAT: THE PRIVATE SECTOR*

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Presented at the Solar Industrial Process Heat Conference held in Oakland, California on October 31 through November 2, 1979.

ABSTRACT

Four privately funded process heat installations are described. These include: Anheuser-Busch's brewery in Jacksonville, Florida; Andy's Solar Truck and Car Wash in Mesa, Arizona; EASCO photo processing laboratory in Richmond, Virginia; and General Extrusions in Youngstown, Ohio. These four systems have similar economic and operating characteristics to the first generation of DOE funded field experiments.

INTRODUCTION

The main emphasis of these proceedings is the Department of Energy's program to develop and promote the use of solar energy in industrial process heat applications. This program is carried out through a variety of research programs and field projects which are reported elsewhere at this conference. We would do well to remember, however, that the final object of this entire activity is to have solar IPH systems installed by private industry without any form of direct government funding. This paper examines those few solar IPH systems that were installed with private capital.

There are two projects which are indisputably industrial process heat applications: Anheuser-Busch's brewery in Jacksonville, Florida, and General-Extrusions anodizing line in Youngstown, Ohio. I have included two other operations in this paper that are on the borderline between industrial and commercial operations, but are instructive, nonetheless: EASCO photo processing laboratory in Richmond, Virginia and Andy's Solar Truck and Car Wash in Mesa, Arizona.

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Project Descriptions

Andy's Solar Truck and Car Wash: This is actually a combination of three installations in the Phoenix area. The application is a coin operated car wash where you drop your quarter into a slot and get a high-pressure stream of hot water with detergent out of a wand to wash your car. The operation is unattended. The solar water heating system for each of these units consist of some $40m^2$ ($400\ ft^2$) of parabolic-trough concentrators built by Sunpower Systems Corporation of Tempe, Arizona. The original system built in 1975 circulates city water directly through the solar collectors mounted on the roof and into a storage tank. The two more recent systems (built in 1977) circulate glycol solution through the collectors and transfer the heat via a heat exchanger in the storage tank. The water is drawn from the storage tank through a mixing valve that maintains the water temperature below the maximum that the equipment and public safety will tolerate. There are no backup systems for any of these operations.

The systems have performed very well according to the owners. When asked about expansion plans, they said that they are not planning any new installations, but that they would install solar on any new units they build.

Anheuser-Busch: This is a standardized brewery built by Anheuser-Busch in Jacksonville, Florida, to serve the south-eastern U.S. The entire plant, including the structures, is based upon a prototype design located in Columbus, Ohio (more about this below). The solar system consists of some $460m^2$ ($4600\ ft^2$) of Owens-Illinois "Sun-Pack" evacuated tube collectors. The working fluid for the system is softened boiler feed-water. The heated water is circulated through a heat exchanger which heats water in a pasteurizer to 63°C (145°F). Excess energy can either be sent to a storage system or dumped into the boiler feed water system as preheated water. The system supplies about 1/3 of the energy required for one of seven pasteurizers at this plant. Back-up is provided by the plant's own steam system through another heat exchanger.

Probably the most significant detail of this system is its mounting. The system is located on the roof of the pasteurizing building. System support is provided by pipes welded onto the underlying beams and sealed with pitch- pockets. A second set of beams are mounted on the pipes and the collectors are mounted on the beams. The significance of this very standard construction technique is that there was no structural modification to the roof supports. As I noted above, this building was identical to a standard design that Anheuser-Busch intends to be used in many locations in the country, which means that the roof must be stressed for very large snow loads. In sun-belt areas where solar energy is likely to be employed, the smaller roof loading requirements mean that a solar system can be installed without expensive modifications to the entire structure.

The system was installed in February, 1978, by Berry-Wehmiller of St. Louis, Missouri, and has performed very well since then. The plant engineers indicated to me that they were pleased with the system and the obvious care that it is receiving shows that it will likely be in use for some time to come. The only problem that they have had with the solar part of the system was flow stoppage that led to the evacuated tube being thermally shocked, with the predictable failures. The storage system is not working at the present time due to a design problem, but their capacity to dump heat into the boiler feed-water system means that the solar system is doing just fine. Anheuser-Busch is not planning to enlarge this system at this time because of the negative economics of solar energy in this situation.

EASCO: This is a typical photo processing laboratory located in Richmond, Virginia. Hot water at 115°F is required to develop photographic film. This is a new facility designed by Torrence Dreelin, Farthing & Buford of Richmond, Virginia, and the solar water heater is part of a total conservation package for the entire operation, which includes passive heating and cooling of the office and laboratory space, and heat recovery equipment in a variety of locations. The solar water system consists of some 210m^2 (2100 ft^2) of Sunworks flat plate collectors. City water is circulated from a storage tank through the collectors and back to the tank. It is drawn, on demand, from that tank, through a conventional gas water heater that raises the temperature, if necessary, and is then sent to the process. The most significant part of this system is the fact that the collectors are mounted vertically on the side of the building instead of at an angle on the roof as are most other process type applications. In this case, it was determined that there would be a significant improvement in the cost effectiveness of the system by eliminating the additional hardware needed to mount the collectors at an angle instead of just hanging them on the wall.

The system has had some of the typical problems that are plaguing many new solar water heaters including freeze damage and degradation of the absorber surface (Sunworks uses a selective surface); however the owners are still pleased with the system and intend to increase its size if they enlarge the plant. The building structure was stressed to support collectors on the roof if desired. Further, the owners are involved in a number of other consumer services in the area including retail gasoline, car washes, and laundromats , and are exploring the possibility of using solar on some of their other installations as well.

General Extrusions: This is an aluminum extrusion and anodizing plant located in Youngstown, Ohio. This system is more complex than the first three in that the solar collectors are tied into the process (a cleaning tank for the anodizing line) through a heat pump. Oil is circulated through about 300m^2 (3000 ft^2) of line-focusing concentrating collectors. These collectors have a fairly low concentration power and are tracked seasonally. The oil is then sent directly to the evaporator side of an industrial heat pump. The condenser side of the heat pump heats the cleaning solution used in the first stage of the anodizing process. Back-up heat is supplied by a gas flame. Energy storage is accomplished by over heating the process tank during periods of high irradiance. Because this was a first of a kind system, it was plumbed to operate in a variety of modes.

The system was installed in 1977 by General-Extrusions and has performed very well since that time. Indeed, additional through-put in the process line can be achieved when the cleaning tank is operated at its highest temperature. They do not plan to expand the system at this time because of the economic factors.

CONCLUSIONS:

There are no really startling differences between the Solar IPH systems installed with private funds and those that have been installed at DOE expense. All of the systems are small, less than 5000 ft^2, and tend to be somewhat more complex than absolutely necessary because of a desire to try out a number of different ideas at one installation. There are no surprises in the area of economics. When working in optimum conditions and at fairly low temperatures, solar systems provide at least a modest return of investment. At higher temperatures, the returns diminish very quickly for these first generation systems.

Operationally, these systems seem to have fared a little better than some of DOE funded projects. This is likely due to the fact that the owner's own money is sunk into the project and therefore the management commitment to care for the system is substantially greater.

In short, some sectors of private industry are extremely interested in solar energy as a possible option to rising fuel costs and possible shortages in the future, but until the economic climate is altered to make solar energy competitive with conventional energy sources, there will not be a mad dash to install large IPH systems.

ACKNOWLEDGMENTS

I would like to thank all of the people who gave so generously of their time to me over the phone and in their plants. These include: William Matlock of Sunpower Systems; Vince DeGennaro, Bob Knott and John Wilson of Anheuser-Busch; Orin Murray of Berry-Wehmuller; Richard Hankins of Torrence, Dreelin, Farthing and Buford; Claud Kinder of EASCO; and Duane Rost of General Extrusions. The facts in this paper are theirs; any errors are mine, alone.

NEW DOE-FUNDED PROJECTS

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Abstract

During FY 79, two Program Opportunity Notices (PON's) and one Request for Proposals (RFP) were issued by the Department of Energy for the design, construction, and operation of solar systems for industrial applications. As the result of the two PON's, six firms were selected to produce industrial systems in the temperature range 212°F to 550°F and sizes ranging from 30,000 ft^2 to 250,000 ft^2. Those firms awarded contracts for solar industrial process heat systems (30,000 to 50,000 ft^2) in the temperature range 212°F to 550°F were Bates Container, Inc., Columbia Gas System Service, Hilo Coast Processing Co., and Southwest Research Institute. Two contracts were awarded for the production of steam for Solar Enhanced Oil Recovery operations of temperatures to 700°F and sizes approaching 250,000 ft^2. Responses to the RFP are currently being evaluated for industrial process heat systems below 212°F and 30,000 to 70,000 ft^2 in size.

Introduction

The Agricultural and Industrial Systems (AIS) Branch under the Assistant Secretary, Conservation and Solar Energy, has as its goal the acceleration of the commercialization of solar energy systems for applications in the agricultural and industrial sectors. To accomplish this, the AIS Branch has a three point program to address the major economic, technical, and market barriers. Field tests to demonstrate the technical feasibility of these solar industrial systems are a vital part of the program. These tests provide a measure of program effectiveness in determining system performance, reliability, maintainability and economic viability.

In FY 79, the major thrust in field tests was in large scale cost-shared systems to determine the degree of economies of scale that could be achieved. Two Program Opportunity Notices (PON's) and one Request for Proposal (RFP) were issued covering the temperature range from 120°F to 550°F and sizes from 30,000 ft^2 to 250,000 ft^2. The two PON's resulted in the selection of six firms to design solar energy systems for industrial applications. Detailed descriptions are presented in the following sections. Evaluations of the responses to the RFP are still being conducted and selection of the firm(s) for negotiation will be announced shortly.

Cost-Shared Field Test (212°F - 550°F)

On April 26, 1979, a PON was issued for the design, construction, and operation of solar systems for industrial process heat applications in the temperature range 212°F to 550°F. As a result of this solicitation, four firms were selected for negotiation to design with an option to construct and operate solar industrial systems in the sizes ranging from 30,000 to 50,000 ft^2. A description of these systems with their application is presented below.

Bates Container, Inc.

Bates Container Incorporated has proposed to install a linear parabolic concentrating solar collection system at the Bates cardboard corrugation fabrication facility in Fort Worth, Texas. Bates has obtained as subcontractors for system design and integration, the BDM Corporation, located in Alburquerque, New Mexico.

Bates is involved in the production of cardboard containers for use in a number of processes. Bates is in the process of expanding their facilities to include a cardboard corrugation fabrication facility to supply the cardboard stock required for the manufacture of various containers which they produce. Corrugating machinery uses steam to precondition, heat, glue, and finally, dry the paper and cardboard product. Typical production levels require between five and six thousand pounds of 175 psi (370°F) saturated steam per hour.

The proposed solar energy system will utilize linear parabolic trough concentrators to provide thermal energy to a nonfired steam generating unit which in turn will produce the requisite steam for the corrugation assembly. The solar collector proposed will be the T-700, fabricated by Solar Kinetics, Inc., of Dallas, Texas which is a 7-foot width aperture with a 90° rim angle. The collector array will be mounted on the roof of the corrugation facility because it appears to be the most cost effective approach to the current application. It is estimated that the solar system will be able to produce 241,900 Btu/ft^2/yr and that the cost of energy delivered will be $144 per million Btu/yr.

A total of 34,720 square feet of aperture is proposed for this application. It has been determined that with the available insolation in the Dallas Fort Worth area, this amount of collectors will produce about 5500 pounds of saturated steam at the required conditions. Typical demand of the corrugation machine is around 5000 pounds per hour. The solar collectors will operate with an outlet temperature of 500° F. Each collector row will be a total of 160 ft. in length, and there will be a total of 31 rows. The thermal working fluid will be Therminol-55 and will be transported through the fluid/heat transport subsystem to the non-fired steam generator located in the mechanical room within the building.

The nonfired steam generator will be a kettle-type generator and it will be controlled with a pressure actuated valve. Steam will be released from the nonfired steam generator into a steam manifold and supplied to the corrugation unit. A control valve will mix the steam from the solar system with that provided by the conventional fossil boiler unit. About 60 percent of the steam produced and supplied to the corrugation machine is consumed during the process. The remaining 40 percent is returned as liquid to the condensate tank where water makeup is provided. This fluid is then recirculated through a feedwater pump which provides the required boiler operating pressures. The instrumentation and data acquisition system is designed such that after completion of Phase III in the program, the data acquisition system may be removed and the solar system will continue to operate as designed.

Columbia Gas System Service

Columbia Gas has teamed with United States Steel to design a solar energy system producing 150 psig steam for use in the production of polystyrene at the USS Chemicals Plant in Haverhill, Ohio. The Haverhill complex uses large quantities of steam at pressures ranging from 20 psig to 450 psig. The average sendout from the central steam plant is 600,000 lbs/hour, of which 75,000 lbs/hour is used at 150 psig. The solar energy system will interface the 150 psig steam header in the polystyrene facility which has a 24 hr, 365 day per year operation. The solar system is proposed to supply steam to the process at $373^{\circ}F$ and produce 8.3 billion Btu's/year at an estimated $253/MMBtu/yr.

Columbia Gas will be performing the solar system design in this team arrangement with USS Chemicals supporting in the area of plant/solar system integration. General Electric is proposed as the collector manufacturer and H.A. Williams & Associates, Inc. as consulting engineers.

General Electric TC-300 low concentration ratio parabolic collectors have been proposed for the $50,000\ ft^2$ ground mounted collector array. Gulf Synfluid 4cs will be pumped at $440^{\circ}F$ from the collectors through 275 ft of overhead piping to the solar system generator immediately inside the polystyrene plant building. In the proposed closed-loop system, temperature sensor will maintain a diverting valve in a bypass position until the heat transfer fluid temperature exceeds the temperature of the steam generator. After the fluid temperature in the solar loop exceeds the steam generator temperature, the temperature sensor will act to direct fluid to the steam generator. As the condensate in the steam generator is heated it begins to flash to steam. The steam generator will provide 10,000 lbs of steam per hour at 165 psig with 504 gpm of Synfluid 4cs entering at 440°F. No thermal storage is required.

Hilo Coast Processing Company

The Hilo Coast Processing Company (HCPC), owned and operated by a cooperative of sugarcane growers, has proposed a solar system on their own plant in Pepeekeo, Hawaii. Hilo Coast will perform project coordination and management with TEAM, Inc. performing the system design and integration. The University of Hawaii has proposed to participate in data acquisition and reduction.

The HCPC facility is used to wash, grind and extract sugar from a locally grown sugarcane. The facility operates 24 hours a day seven days per week with an 8-hour per week down period for maintenance. HCPC's grinding season is 45 weeks per year.

The major steam requirements of the industrial process are to supply power to the mill turbines in the milling process and heat for evaporating water from the extracted juices. Steam quality and flow rates for the respective processes are 400°F, 165-170 psi, 160,000 lbs/hr; and 240°F, 12 psi, 40,000 lbs/hr.

Bagasse (the fibrous residue of milled sugarcane) supplied 77% of the fuel requirement for steam generation in 1978; 96,782 barrels of bunker C fuel oil made up the reamining 23%. These fuels are burned in a power plant complex which produces 825°F, 1,250 psi superheated steam to power a turbogenerator set which, in addition to serving the factory, generates from 7-16 megawatts of electricity that is exported to the local utility company. The exhaust steam from the turbo-generator set is used in the industrial process; however, during normal operation this exhaust steam does <u>not</u> meet the steam requirements for the total process. Additional steam must be produced which bypasses the turbo-generator and flows directly to the processing stations. It is this additional steam requirement that the proposed solar system will supplement at a delivered energy rate of 13.3 Billion Btu/year.

The solar system will incorporate 50,400 ft^2 of ground mounted Solar Kinetics T-700 parabolic trough, line-focusing solar collectors. The collector's tracking axis will be oriented north-south and will track the sun from east-west. Therminol 55 will be used as the heat transfer medium and will exit the collector field at 480°F. A constant exit temperature will be maintained by varying the flow rate through the field depending on available insolation. A solar-fired steam boiler will act as an oil-to-steam heat exchanger with the water being supplied from the factory's condensate storage tank. Steam quality exiting the heat exchanger will be 400°F, 165 psi. This is compatible with the steam quality for the turbine in the mill. The solar generated steam will be divered to the evaporation process after it exits the mill turbines. No thermal storage will be added.

Even though bagasse is the primary fuel for the additional steam requirements of the facility, direct fuel oil savings will result from the solar system since any bagasse that is "freed-up" by the solar system can be stored in existing warehouses and burned when fuel oil would otherwise be used. Estimated cost of the energy delivered is $108/MMBTU/year.

Southwest Research Institute

Southwest Research Institute will design a solar system for the Caterpillar Tractor Co. in San Leandro, California where the current 325°F/100 psi process steam plant is being replaced by a new facility with a lower temperature pressurized water system at 235°F/30 psi. Southwest Research Institute and Caterpillar Tractor Co. in combination will perform the total project scope.

The San Leandro plant produces a variety of engine components for use in Caterpillar diesel engines. In this manufacturing operation the major energy consumption is for washing industrial parts prior to inspection. Integrating a solar system into the low temperature pressurized water system could provide 62% of the instantaneous plant load under clear sky condition, however on a yearly basis the solar contribution would be about 18% due to the fact that the plant operates 24 hours a day. The proposed system should produce 19 billion Btu/year. Estimated energy cost for the proposed system is about $80/MM Btu/year.

Hot water for the plant process heat system is generated in the natural gas fired hot water boiler and is then pumped through a hot water supply header that rings the building. Every 40 feet there is a 2-inch valved outlet for connection to process equipment and an accompanying 2-inch valved inlet to the hot water return header. The cooled process water is then returned to the boilers via feed pumps.

The solar system to be designed will tap the hot water return line which is about 195°F, pump the process water directly through the collector field, and return it to the hot water supply line at 235°F. Since the two lines are at relatively constant temperature, the control scheme is to vary the flow rate to hold the temperature rise across the collector to a constant 40°F from 195°F to 235°F by either a variable speed pump or a throttling valve. The maximum required flowrate for a 40°F temperature difference is 836 gpm. This system eliminates the need for auxilliary equipment such as heat exchangers, boilers, sophisticated control systems, storage tanks or expansion tanks.

The collector field will be four banks of fifteen 120-ft long rows each of Solar Kinetics T-700 collectors. This concentrating collector field will be 50,400 ft^2 and built on half of the available roof area of the Caterpillar plant. At present it appears that the roof structure will not require any additional structural steel, and that the I-beam joists will be more than adequate to support the field loads.

An industrial automatic data logging system in combination with a small on-site data processing computer is included in the design to accurately determine the performance of the solar system.

Cost-Shared Field Test (212°F)

A Request for Proposals was issued on June 29, 1979, for the design, construction, and operation of solar systems for industrial process heat applications in the temperature range below 212°F. Thirteen proposals have been received as a result of this solicitation and are currently being evaluated. It is anticipated that selection for negotiation will be announced by mid-November.

Solar Enhanced Oil Recovery (SEOR)

On March 8, 1979, a PON was issued to solicit proposals for the preliminary design, construction, and operation of solar systems capable of replacing the function of a conventional oil-fired steam generator in the 19-25 million Btu/hr. class for steam injection enhanced oil recovery operations. As a result of this solicitation, two firms have been selected to provide preliminary designs with an option to construct one system for the recovery of oil using solar generated steam. A brief description of these two projects is presented below.

General Atomic Company

General Atomic Company (GA) - with PetroLewis and Ametek, Straza Division (A/S) proposed use of a site leased by PetroLewis in the North Kern Front Field located approximately six miles north of Bakersfield, California. The North Kern Front Field is one typical of California fields where thermal enhanced oil recovery operations are presently being carried out and has been subjected to both steam soak and steam drive operations. The existing operation uses two 25 MM and one 50 MM BTU/hr. oil-fired steam generators which disperse steam via a fixed piping system to injection wells. PetroLewis plans to install six more 50 MM BTU/hr. steam generators and it estimates that with these added generators the economic life of the field is ten years.

The system envisioned by GA would be a solar/fossil hybrid with a combined annual average output of 25 MM BTU/hr. The solar unit would consist of 235,000 square feet of GA's Fixed Mirror Solar Concentrator (FMSC) collectors located on 12 acres of land adjacent to the oil recovery operations. The FMSC modules will be positioned in an east to west array. The heat collected in the receiver will be removed by a heat transfer fluid to a conventional oil-water steam generator. Steam at 545 degrees Fahrenheit and 80% quality will be produced and supplied to the common steam header. One of the existing 25 MM BTU/hr. oil-fired generators will be paired with the solar system to provide steam when the sun does not shine. The proposed piping arrangement allows for solar or solar/fossil hybrid operations in either steam soak or steam drive modes.

The management scheme would have the prime contractor to DOE, GA, perform as Project Manager. Two major subcontractors to GA would be PetroLewis, as system user/operator of the oil field, and Ametek, Straza Division (A/S) as mechanical fabricator for process development and collector production.

Exxon Research and Engineering Company

Exxon Research and Engineering Company (Exxon) - Exxon (with Foster Wheeler Development Corporation (FWDC) and Honeywell, Inc. (HW) proposed use of its Edison field seven miles southeast of Bakersfield, California, for the construction and operation of a solar fossil hybrid steam generation plant with a combined annual average output of 26 MM BTU/hr. The solar unit would consist of four separate quadrants with a total of approximately 254,000 square feet of tracking parabolic trough-type solar collectors located on 40 acres of land interspersed among the oil wells. A firm collector design would be established and selected during the Phase I effort.

A conventional oil-water steam generator would be used to produce 500 degree and 80 percent quality steam. One fourth of the collectors would be used to preheat the boiler feedwater while the other three fourths of the collectors would utilize a heat transfer fluid to produce steam from the preheated feedwater in the conventional oil-water steam generator. The collectors would be oriented along a north-south axis to maximize energy collection. Each quadrant of collectors would have separate controls and instrumentation and the solar steam system would be paired with existing oil-fired boilers via a fixed pipe distribution system for the conduct of steam soak operations (huff-puff). Use of a steam drive operation to extend oil field life from the present estimated six years will depend on the results of present ongoing studies and field tests by Exxon.

FWDC would be the subcontractor responsible for the construction phase of the project while HW would be the subcontractor to provide solar collector expertise. Exxon would be the prime contractor with DOE and would operate as the Program Manager through an operations committee with a rotating chairperson during each phase of the work.

Poster Session

Contributed

SOLAR INDUSTRIAL PROCESS STEAM: AN ECONOMIC ANALYSIS

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ABSTRACT

An analysis using a discounted-cash-flow technique was performed to evaluate the economic viability of the solar industrial process steam system utilizing concentrating distributed collectors which will be installed at Dow Chemical Company's Latex Manufacturing Plant in Dalton, Georgia. The influence of tax incentives, capital structure, depreciation method and period, potential reductions in the cost of such systems, and inflation rates were examined. A particularly important parameter in this analysis was found to be the differential between anticipated inflation and fuel cost escalation rates. Conclusions were drawn as to the circumstances in which such solar steam systems will prove to be economically attractive to process industries.

INTRODUCTION

It is estimated that solar thermal energy could fill 20 percent of the total industrial process heat demand in the year 2000[1]. However, this potential is limited by the availability of land for siting solar collectors, institutional factors, and economic considerations[2]. The last aspect is the subject of this paper: the application of discounted cash flow analysis to a system demonstrating the solar generation of industrial process steam is described together with measures that influence the attractiveness of such systems to industry.

ECONOMIC ANALYSIS--THE DISCOUNTED CASH FLOW TECHNIQUE

The use of discounted cash flow techniques is important in the evaluation of new technologies where cash flows differ markedly from those in conventional systems. The determination of the profitability of a process using discounted cash flow criteria can be made without the subjectivity associated with traditional methods for the assessment of the profitability of invested capital. Discounted cash flow analyses inherently make provision for the recovery of capital expenditures. In such analyses, the discount rate used reflects both the time value of money and the uncertainty of future cash flows.

To perform discounted cash flow analyses, a computer program based upon Salmon's work [3] was used. This program allows for considerable flexibility in the handling of investments, capital structures, operating expenses, and taxes. In addition, our program can handle inflation, and cost escalations. This ability is especially relevant to the analysis of solar projects whose viability depends upon rapidly escalating energy costs to offset high initial capital costs.

It should be noted that the discounted cash flow rate of return on equity quoted in these studies is not given as a rate over and above the rate of inflation.

THE PROJECT--SOLAR INDUSTRIAL PROCESS STEAM

As part of the U.S. Department of Energy's program to stimulate the development of solar energy, a number of solar process steam demonstration plants are to be built. One of these is to be installed by Foster Wheeler Development Corporation at Dow Chemical Company's Latex Manufacturing Plant in Dalton, Georgia. The economic analysis described in this paper was performed for this system.

This solar plant utilizes state-of-the-art technology to generate saturated steam at 185°C (365°F). It consists of a loop that delivers a hot organic fluid from parabolic trough solar collectors to a steam generator and returns the fluid to the collectors via a circulating pump. The most cost-effective operating conditions and components are used. It will, however, serve only to reduce consumption of fossil fuels rather than to reduce capital expenditure on a boiler. The system is described in greater detail elsewhere[4].

RESULTS OF THE ANALYSIS

This economic analysis demonstrates that the attractiveness of a solar process steam system to industry is dominated by the capital expenditure required of industry, tax and depreciation policies, and the escalation rate of fossil energy costs. The capital expenditure required of industry is determined by the capital cost, tax credits and cost sharing, and capital structure. These and other variables will now be examined in detail. The data for this analysis are presented in Table 1.

Capital Costs

The influence of capital cost on the expected rate of return on equity was investigated. A capital cost of $500,000 is anticipated for such a distributed collector system once mass production is achieved. A capital cost of $400,000 is a most optimistic estimate as 50 to 75 percent of the total installed system cost is derived from equipment for which few future economies can be expected. Furthermore, there are few economies of scale; collector and piping costs are essentially proportional to the installed collector area.

The analysis shows that with a $400,000 capital cost, an escalation rate in fuel costs of 14 percent per year is required if a 10 percent rate of return on equity is to be achieved.

TABLE 1 DATA FOR THE ECONOMIC ANALYSIS

Variable	Range Studied	Value Used Unless Otherwise Stated	Remarks
Capital Costs	\$400,000-\$700,000	\$700,000	Includes cost of 940 m^2 of collectors
Capital Structure	Debt-to-equity ratios of 1:1 and 0:1	100% equity funding	
Tax Credits	20-80%	20%	
Federal Taxes	0 and 46%	46%	Negative taxes can be charged
State and Local Taxes		4%	
Depreciation Method		Sum of years digits	
Depreciation Life	1-20 years	20 years	
System Lifetime	20-30 years	30 years	
Working Capital		\$1,000	
Insurance Costs		\$1,000/yr	
Operating Costs		\$180/yr	No additional manpower is required.
Maintenance Labor Costs		\$3,240/yr	
Replacement Costs		\$2,780/yr	
Annual Energy Cost Escalation Rate	7-17%		
Other Inflation Rates		7%	
Current Energy Costs		\$2.84/GJ	

*Costs given are in 1978 dollars.

Tax Credits and Cost Sharing

Cost sharing provides a route by which the capital expenditure required of the industry can be reduced. As such, it is equivalent to the provision of tax credits--50 percent cost sharing with a 20 percent tax credit is equivalent to a 60 percent tax credit. With an 80 percent tax credit, a 10 percent rate of return on equity was achieved at an annual rate of inflation in oil costs of 9.6 percent. With a 20 percent tax credit, an annual rate of inflation in oil costs of 16.8 percent is required for the same return.

Capital Structure

Debt funding of a project is advantageous provided the after-tax cost of the debt is less than the discounted cash flow rate of return. In this solar project, as the return on equity is unlikely to exceed the minimum required by industry, debt funding of the investment is desirable, the required rate of return being greater than the after-tax cost of the debt. Thus at a debt-to-equity ratio of 1:1 and with debt funding at 6 percent (representative of tax-free bonds) a 10-percent-per-year rate of return on equity was achieved at a 12.8 percent per year inflation rate for fuel.

Depreciation Period

One incentive to encourage investment in solar process steam systems is to permit more rapid depreciation. A reduction in depreciation period from 20 years to 1 year reduces the escalation rate in energy costs required to achieve a 10 percent return on equity from 16.8 to 15.4 percent.

System Lifetime

As the system lifetime is extended, the anticipated rate of return on equity increases. It should be noted, however, that the reliability and lifetime of collectors are unproven.

Income Tax

The installation of a solar system will result in a savings in other fuel costs. The payment of income taxes on the profits derived from this detracts from economic viability of solar energy. If no tax were paid, a 10-percent-per-year rate of return on equity is achieved at a 14.8 percent per year escalation rate in other fuel costs in contrast to the 16.8 percent per year otherwise required.

CONCLUSIONS

A discounted cash flow analysis technique has been used to examine the influence of various factors upon the rate of return on equity anticipated for a solar process steam system. Any conclusions drawn as to the scenarios in which solar steam systems are economically attractive must be accompanied by a critical evaluation of those scenarios. In particular, the economic viability of solar steam systems requires fuel cost escalation rates to be in excess of the overall rate of inflation over the 20-to-30-year life of the project.

If a discrepancy in inflation rates can be assumed, and the criteria of economic attractiveness is defined as a 10-percent-per-year rate of return on equity, then distributed collector solar steam systems will be attractive given combinations of tax credits, low interest debt funding, accelerated depreciation, elimination of income tax on the income created by the reduction in other fuel purchases, and a rate of escalation in fuel costs that exceeds the general inflation rate. These conclusions are graphically shown in Figure 1. Without large escalation rates in fuel costs, measures other than tax credits or cost sharing are unlikely to be sufficient. With these incentives, however, other energy systems will probably be more attactive. It should be added that there may be other special circumstances where distributed collector solar steam systems are viable.

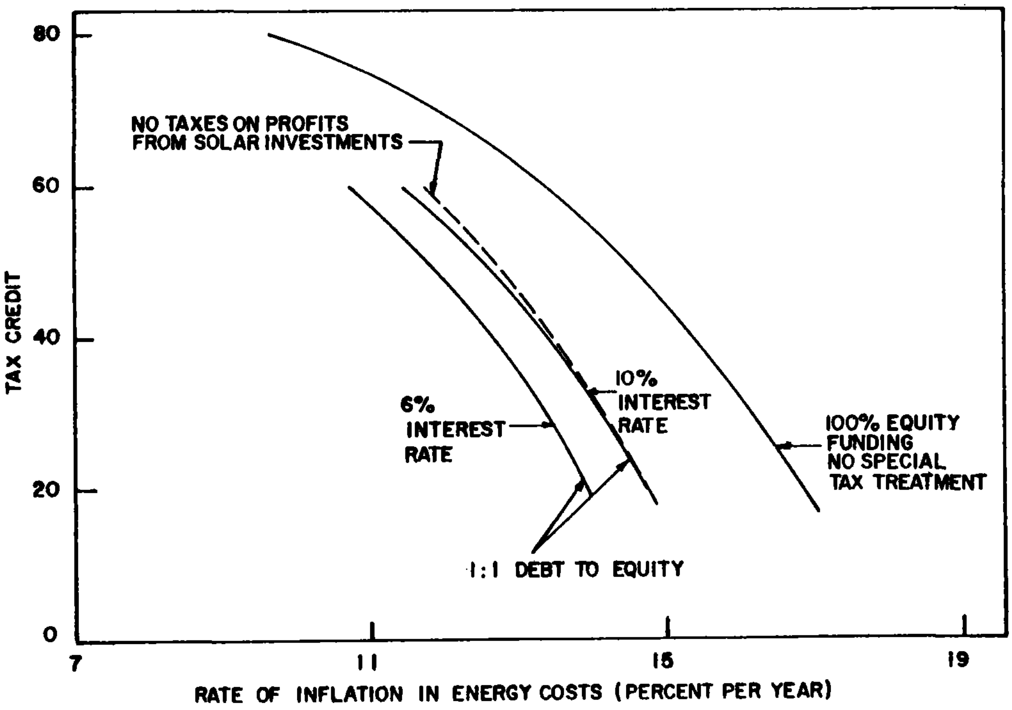

FIGURE 1 CIRCUMSTANCES IN WHICH SOLAR STEAM SYSTEMS ARE ECONOMICALLY ATTRACTIVE

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REFERENCES

1. Battelle Columbus Laboratories, "Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat," prepared for U..S. Energy Research and Development Administration, Report No. ERDA TID-27348/1, 1977.

2. A. B. Casamajor and R. L. Wood, "Limiting Factors for the Near-Term Potential of Solar Industrial Process Heat" Solar Industrial Process Heat Conference, October 18-20, 1978, Vol. 1, pp 175-185, Report No. 781015.

3. R. Salmon, "PRP-A Discounted Cash Flow Program for Calculating the Production Cost (Product Price) of the Product from a Process Plant," ORNL-5251, Oak Ridge National Laboratory, March 1977.

4. Foster Wheeler Development Corporation, "Final Report for Solar Production of Industrial Process Steam Ranging in Temperature from 300°F to 550°F (Phase I)," prepared for U.S. Department of Energy under Contract ET-78-C-03-2199, June 1979.

THE ADVANTAGE OF LOAN LEVERAGING IN COMMERCIAL SOLAR PROCESS HEAT APPLICATIONS*

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ABSTRACT

In a majority of the solar/thermal studies to date, a utility economic methodology has been used to assess the potential of solar power systems. The utility sector is precluded from taking advantage of loan leveraging because the effective rate of return is artificially set. Utilities are regulated by public commissions and thus must finance new capital investments according to a prescribed set of rules on after tax cost of capital and fixed charge rates.

Commercial ventures have no such externally imposed constraints and make decisions for capital expenditures which include the effect of loan leveraging. The relevant parameters for a commercial institution are interest rate on debt, a discount rate which accounts for risk, and the effect of favorable tax incentives. In the present study, an expression is developed for a capital cost factor which contains these parameters. Results are shown for various downpayments and discount rates. It will be shown that the effect of loan leveraging can be substantial in affecting the penetration of solar process heat into the commercial energy market. In addition, the relation between loan leveraging and risk is investigated.

INTRODUCTION

Solar energy has historically been viewed in the context of repowering investor-owned electric utilities. Because of this, a utility economic methodology [1] which requires the rate of return on investment (discount rate) to be equal to the effective regulated cost of capital has been used to assess the potential of solar thermal power systems. The very nature of the utility sector precludes taking advantage of loan leveraging. Utilities are regulated by public service commissions and thus must finance new capital investments according to a prescribed set of rules on after tax cost of capital and fixed charge rates. This allows the utility to return a predetermined amount to its investors and prevents electrical energy charges from being excessively high.

The most common method used by large corporations to borrow money is the selling of corporate bonds. The stream of expenditures associated

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with this debt is a series of constant interest payments and a single payment to retire the principal at maturity. However, it would be a mistake to evaluate the present value of this payment series using the conventional corporate discount rate. The total indebtedness of a company is usually limited by the debt-equity ratio for that company (typically .4), which is determined by considerations that are unrelated to the risks of the particular project being considered. The standard practice in industry is simply to assume each investment shares a proportionate amount of the company's total debt, and to evaluate all investments as equity financed. The fact that part of the money invested is borrowed is reflected in a higher value of the discount rate. The implication is this: explicit discounted cash flow analysis of loan payments is only appropriate when the loan does not contribute to the balance sheet indebtedness of the investing organization. Mechanisms which accomplish this feat are known generically as project financing [2]. There are many strategies for project financing but the example implicit in the analysis to follow would be a government guaranteed loan program which would allow a company to borrow far beyond and independent of its conventional credit capacity. (However, it should not be assumed that the interest rates are artificially low.)

The relevant discount rate to be used in a discounted cash flow type analysis is a quantity which reflects the rate of return desired by the investor. It is often taken as being the opportunity cost of money or the rate an investor could receive by investing in his next best alternative. This nominal discount rate should include a component for inflation in addition to a real rate of return. The element of risk in a particular investment can also be accounted for in this quantity. Typical commercial discount rates on solar/thermal systems are expected to be at least 15% and perhaps as high as 25%. This is indicative of the perceived uncertainty in the reliability of these young power systems. For a coal-burning plant, a lower discount rate would usually be required. In fact, the typical after tax cost of capital or equivalent utility discount rate is perhaps 8% to 12%. In the present analysis, it will be shown that the higher discount rate which prevails in the case of solar/thermal systems can be made to be an advantage under the proper loan leveraged situation. This will require reasonably low down-payments with moderate interest rates when compared with the discount rate.

To simplify the notation which is always cumbersome in a discounted cash flow analysis, the present work attempts to scrupulously follow the notation and methodology of reference [3]. A desired result of this paper is to present a cross-reference between the commercial [3] and utility [1] methodologies. It has recently come to the attention of the authors that reference [4] has also attempted to bridge this gap. Reference [4] has, however, concerned itself more with the mechanics of the correspondence between methods rather than the fundamental economic differences.

ANALYSIS

The annualized cost of energy production consists of two components; the initial cost and the recurrent costs components.

$$\overline{AC}_c = ICC + RCC \tag{1}$$

It is customary to express the initial cost component as a capital cost factor times the present value of the capital investment. For a single investment in the first year of operation of the plant, the present value is equal to the initial capital investment. For multiple investments, the methodology outlined in [1] or [3] can be used to "present value" the capital outlays. If there is a construction period over which expenses are being incurred but no energy is generated, this must be accounted for by interest during construction.

The initial cost component is defined as

$$ICC = CCF \cdot IC \tag{2}$$

where CCF is the capital cost factor and IC is the present value of the capital investment, or in this case, the single initial capital investment. This CCF includes factors to account for the financing method, a present value factor to account for plant depreciation and any investment tax credits. In reference [1], this CCF plus the property tax and insurance rate is called the fixed charge rate. A precise definition of the CCF is given in equation (3).

$$CCF = CRF(d,Ns)\ [F - \tau \cdot DPF - \alpha] \tag{3}$$

where F is the financing method factor,
τ is the effective tax rate,
DPF is a plant depreciation factor,
α is the investment tax credit, and
CRF is the capital recovery factor.

For a capital intensive facility such as a solar thermal/electrical generating plant, it is desirable to reduce the initial cost component as much as possible (provided of course that the recurrent costs do not greatly increase as a result). It is therefore relevant to investigate the dependence of the CCF upon its major parameters. To keep this exercise simple, it will be assumed that a very favorable depreciation schedule applies, namely a 7 year depreciation life using sum-of-the-years digits. In addition, a 25% investment tax credit is assumed to be applied to the system. Both of these assumptions are favorable, but not unrealistic especially if market penetration of solar energy is desired by the government. Defining the system life time as 20 years with zero salvage value and an interest rate of 10% with a general inflational rate of 8% permits calculation of the CCF as a function of downpayment, D, and discount rated. This is presented in Figure 1 with CCF versus D at various discount rates. For comparison, a utility could be as low as $d = k = 8\%$, and $D = 100\%$. Note that this low discount rate is set by the regulatory commission to result in a certain return on investment to the utility stockholders and reflects risk and investment strategy in only a secondary way. If three downpayments, namely 100%, 40%, and 20%, are now specified, the CCF can be calculated as a function of discount rate. This is highlighted in Figure 1. Note that as mentioned earlier, even for these favorable economic assumptions, increasing discount rate results in increasing CCF for 100% downpayment. For 40% down, however, not only is the value of CCF less at an 8% discount rate, but it is further reduced as the discount rate increases. The 20% down line further amplifies this effect. Since 15% is a more typical discount rate for a commercial operation, it is clear that a large reduction in CCF can be obtained for low downpayments.

LOAN LEVERAGING AND RISK

It is a common belief that while loan leveraging can increase the expected value of a capital intensive investment it has the financial characteristics of speculation, and the increased risks must be weighed against the expected rewards. It is the intent of the following discussion to show that this is not always true.

It is first necessary to quantify the concept of risk and to consider a specific solar application as an example. For this, a Monte Carlo probability analysis of the economics of Solar Enhanced Oil Recovery (SEOR) has been developed. The SEOR concept and the economic model used in the analysis are fully described in reference [5]. Because the model depends on a large number (23) of parameters, each with some degree of uncertainty, the risks and rewards of an investment in SEOR can be evaluated only with a probabilistic analysis. If each parameter is allowed to vary independently over a specified range with a normal probability distribution, the resulting distribution for the rate of return (ROR) can be determined. The quantitative details will be specified in a future publication [6], but what is more important here is the qualitative nature of the results shown in Figure 2. The increase in the mean or expected value of the ROR when comparing the 20% down case to the 100% down case is as anticipated. In addition, a substantial increase in the variance or spread of the distribution is noted, indicating a higher uncertainty of the outcome. But this is not what is meant by risk. It is the risk of failure that is the concern, and a useful quantification of this concept is to specify a critical rate of return, r_c, as the success-failure criterion. The risk of failure is then defined simply to be the cumulative probability of achieving less than r_c:

$$f(r_c) = \int_{-1}^{r_c} P(r)\, dr \tag{4}$$

where P is the function plotted in Figure 2. It is a matter of judgment what r_c should be, but a reasonable lower bound is the inflation rate, whose mean value for Figure 2 was .07. We find by integration that f(.07) = .209 for 100% down and f(.07) = .109 for 20% down, hence the risk is less for the loan leveraged case than for the equity financed case. It is possible to find other examples (e.g., with different inputs to the Monte Carlo analysis) in which loan leveraging increases the risk. But because of the combined effects of tax deductions on interest and the discounting of delayed payments, loan leveraging increases the expected return and decreases the risk to the investor in many, if not most, realistic cases.

REFERENCES

1. Doane, J. W. et al, "The Cost of Energy From Utility-Owned Solar Electric Systems--A Required Resource Methodology for ERDA /EPRI Evaluations," JPL 5040-29, Jet Propulsion Labs, Pasadena, CA, June 1976.

2. Nevitt, P. K., Project Financing, AMR International, Inc. (N.Y. 1978).

3. Perino, A. M., "A Methodology for Determining the Ecnomic Feasibility of Residential or Commercial Solar Energy Systems," SAND78-0931, Sandia Laboratories, Albuquerque, NM, January 1979.

4. Dickinson, W. C. and Brown, K., "The Economic Analysis of Solar Industrial Process Heat System--A Required Resource/Internal Rate of Returns Methodology," SERI, Golden, CO, to be published, 1979.

5. Bergeron, K. D., "Solar Enhanced Oil Recovery; An Assessment of Economic Feasibility," SAND79-0787 (May 1979), Sandia Laboratories, Albuquerque, NM

6. Bergeron, K. D., "A Preliminary Assessment of Solar Enhanced Oil Recovery," 2nd Miami Int'l. Conf. on Alternative Energy Sources, 10-13 December 1979.

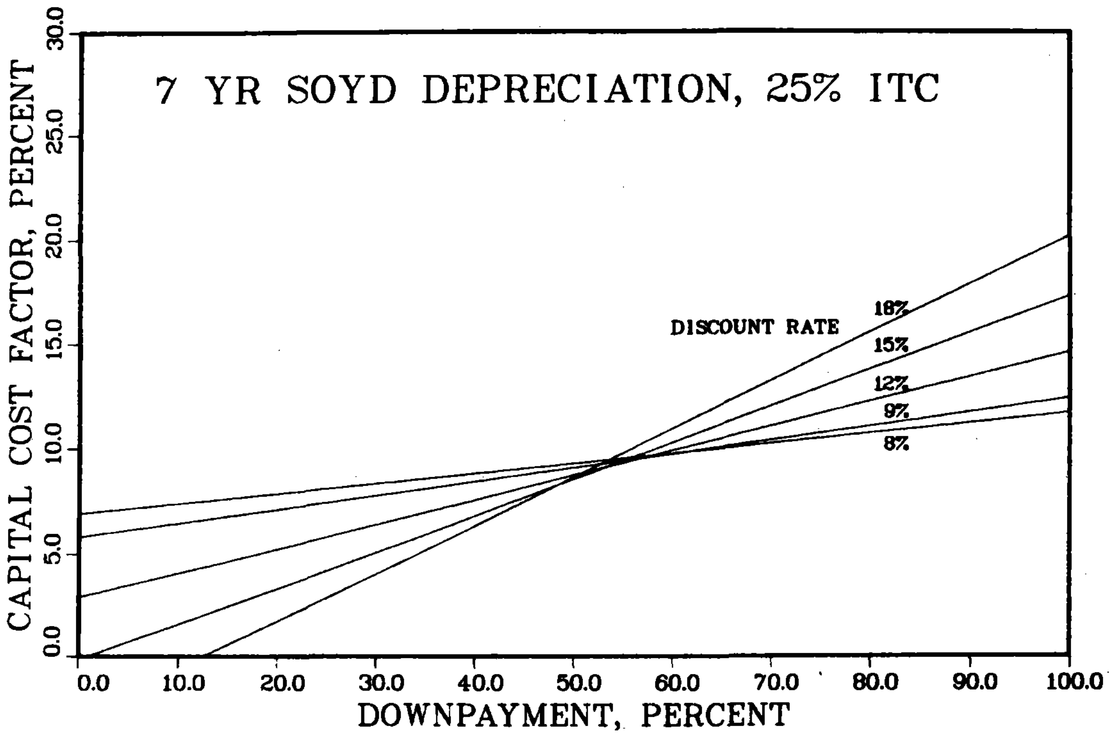

Figure 1. Capital Cost Factor Depending on Downpayment and Discount Rate.

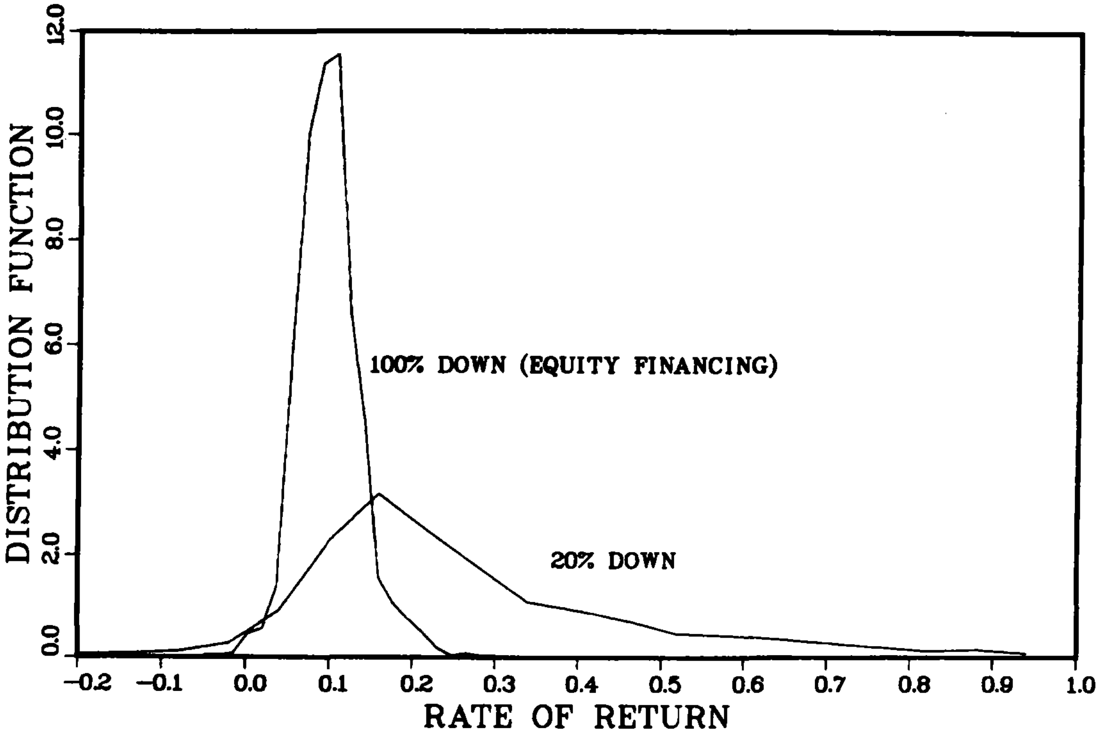

Figure 2. Monte Carlo SEOR Economics.

INDUSTRIAL APPLICATIONS ANALYSIS: MARKET CHARACTERIZATION AND SYSTEM DEFINITION FOR SEVERAL INDUSTRIES

K. C. Brown, P. A. Ketels, S. A. Stadjuhar

INTRODUCTION

The information summarized in this paper is a continuation of efforts initiated at SERI during FY78 pertaining to industrial energy use; it is in response to the need for information that is industry- and site-specific. As solar thermal industrial process heat technology develops, it is increasingly important to identify specific near-term markets for these systems. The markets must be defined in adequate detail, in terms of performance, reliability, and cost criteria, to direct solar-system engineering development and to provide such systems at a cost that industry is willing to pay.

OBJECTIVES AND APPROACH

The primary objectives of the FY79 market characterization/system analysis program were the following:

- characterize the industrial process heat market by industry and location to identify key market sectors,
- select a number of industry categories for in-depth study of technical and economic parameters, and
- evaluate the feasibility of solar applications within the specific industries.

Aggregate market studies and some limited case studies have been completed in the past for industrial process heat utilization both in a general sense and directly related to solar application potential. During the initial phase of the program, studies such as those completed by InterTechnology [1] and Battelle [2] were reviewed and provided the basis for initial assessment of the potential for solar industrial process heat implementation in the United States.

Information in these reports was updated, using later census data, and disaggregated to the state level for purposes of determining geographical locations of industry and plants. The intent of the disaggregation step was to show geographical concentrations of industry. The Great Lakes Region and the state of California were found to be prominent in terms of industrial manufacturing activity. We determined the geographical location of the industries in question (those industries consuming greater than 5×10^{12} Btu of energy annually, at an end-use temperature of less than 1100°F) to illustrate the importance of recognizing the impact of solar insolation levels on the level of conventional fuel displacement. Following the update of energy consumption information, industries were listed according to process end-use temperature requirements. These general preliminary rankings were produced for industries requiring process heat at temperatures less than 550°F and for those requiring heat between 550°F and 1100°F.

The next phase of the program consisted of contacting trade associations to determine the general energy posture of the industry, the availability of information pertaining to both technical and economic requirements, and the degree of cooperation provided through additional information requirements and information dissemination to their membership at the conclusion of the study. All of the above factors were employed as a screening mechanism for selecting the following industries for in-depth analysis: Baking (SIC 2051), Fluid Milk Dairies (2026), Cane Sugar Refining (2062), and Nonferrous Foundries (Die Casting) (3361). Each of these industry groups was analyzed with respect to the feasibility of solar energy application to process requirements. A brief discussion of the results of the analysis for the dairy industry follows.

EXAMPLE: FLUID MILK DAIRIES

The fluid milk industry (SIC 2026) consists of establishments primarily engaged in the processing of raw milk (e.g., pasteurizing, homogenizing, and bottling) and distributing milk, cream, and related products. The total U.S. production of raw milk in 1978 was 119.3 X 10^9 pounds, of which 45% was processed within the fluid milk industry. The remainder was used in butter, cheese, and other processed dairy foods. Since 1960, the number of plants in the fluid milk industry has been declining from a total number of 8,195 to approximately 1,338 in 1979. The location of these plants is shown in Figure 1.

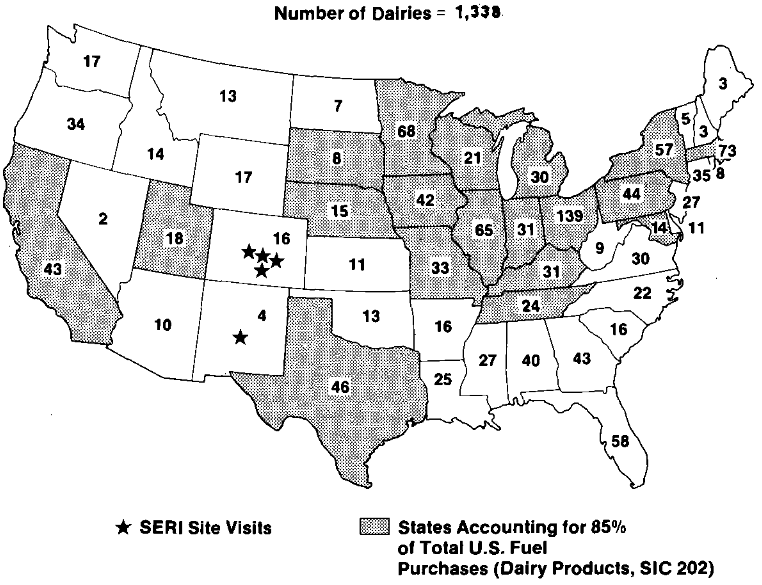

Figure 1. Number of Fluid Milk Dairies by State

The decline in the number of plants is primarily attributed to technological improvements in transportation allowing for the consolidation of many smaller plants into larger processing units. However, in contrast to the general downward trend in the overall number of processing plants, the number of plants operated by integrated supermarket chains has been increasing both in terms of the number of firms and in the number of plants.

Significant regional variations in plant capacity are evident with the larger plants located in or adjacent to the more heavily populated areas which results in a clustering of plants. While the industry generally is market oriented in terms of location, sources of supply still are a location factor and very little raw milk is transported for distances greater than 250-300 miles. The principle fuel used in the industry is natural gas, followed by fuel oil.

Although plant energy use efficiency, product mix, and schedule may vary from plant to plant, the configuration and characteristics of individual processes are relatively uniform throughout the fluid milk industry [1-6]. Typically, process heat is provided by a steam boiler operating at about 65% efficiency. Virtually all of the process heat requirement is for cleanup and product processing. Within product processing, 40-60% of the energy use is for pasteurization. Remaining energy use is determined by product mix and includes milk and whey drying, cottage cheese cooking, and sour cream and yogurt culturing.

The pasteurization process requires heating milk to a temperature of approximately 169°F and holding at that temperature for a short period of time. The old method of vat pasteurization with low temperatures and long holding time has essentially been replaced by HTST (high temperature short time) pasteurization. HTST pasteurization incorporates heat regeneration in which cold milk entering the pasteurizer is warmed by milk leaving the pasteurizer (in turn cooling the outgoing milk), resulting in heat recovery of 80-90%. Pasteurization requires approximately 26 Btu/lb of milk at a temperature of 169°F. Milk can take on odors characteristic of the cattle feed; some producers also subject the milk to a deoderization process at an increased temperature of approximately 185°F. Hot water for cleanup at temperatures of 140°F or lower normally requires 1.5 times as much process heat energy as that required for pasteurization.

Plant size and operation schedule vary considerably throughout the industry. A few large plants produce over 100,000 gallons of milk per day, while a number of small plants produce less than 3,000 gallons per day. An "average" plant size produces between 15,000 and 30,000 gallons per day. Daily operation schedules vary considerably, but in almost all cases at least one shift operates through the daylight hours. The majority of plants appear to prefer a 6-day/wk schedule.

In order to characterize the pasteurization process in sufficient detail for computer analysis, the following assumptions were made. Operation was considered continuous throughout the daylight hours for six days per week. Pasteurization requires 26 Btu/lb of milk (218 Btu/gal) at a temperature of 169°F. The process heat backup is a conventional steam boiler operating at 65% efficiency. The solar system operates in a supplemental fashion, contributing energy as available and sized so that all energy produced at the peak delivery rate is accepted by the process. The solar equipment selected for this analysis was a horizontal parabolic trough collector tracking about the N-S axis in an indirect hot water system configuration. The solar system was integrated into the pasteurization process, shown in Figure 2.

Analysis using the PROSYS/ECONMAT computer code [7] was performed for several plant sizes at 27 locations across the United States. Results included collector performance prediction, annual energy capacity cost, solar equipment cost, net present worth, and payback period. Economic parameters used in the life-cycle cost analyses included a 12% internal rate of return; 6% general inflation rate; 5% add-on fuel escalation rate; annual operation, maintenance, property tax, and insurance at 2% of initial investment; 50% corporate income tax rate; 20-year system lifetime; and 20% tax credit. For a plant processing 3,125 gal/hr, 16 hr/day, 6 day/wk, the solar system supplied 45-60% of the annual

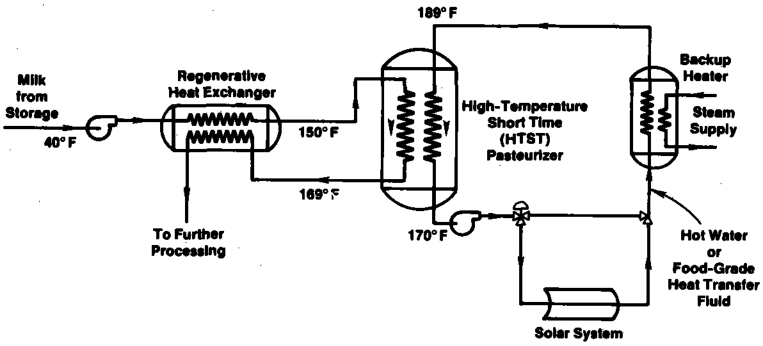

Figure 2. Milk Pasteurizing Process

energy requirement, depending on location. Required parabolic trough array size varied from approximately 5,500 ft^2 in El Paso and Phoenix to over 11,000 ft^2 in Boston, Caribou, and New York. Required fuel price in 1979 dollars was calculated for several payback periods and system start years [8].

For instance, in order to achieve a 10-year payback for a solar system installed in 1985, a plant in El Paso with the above characteristics would require a current fuel price of \$4.00/10^6 Btu (in 1979 dollars). Figure 3 shows the required fuel price at 27 sites for a 10-year payback for 1979, 1985, and 1990 system startup times. Similar analyses show that the same solar system, subjected to a 5-year payback criterion can only compete at best with fuel prices in 1979 dollars of over \$5.00/10^6 Btu for a 1990 startup, over \$7.50/10^6 Btu for a 1985 startup and over \$12.00/10^6 Btu for a 1979 startup. Cleanup hot water in fluid milk dairies is a somewhat more attractive solar IPH application with required fuel breakeven prices approximately two-thirds that of breakeven prices for pasteurization.

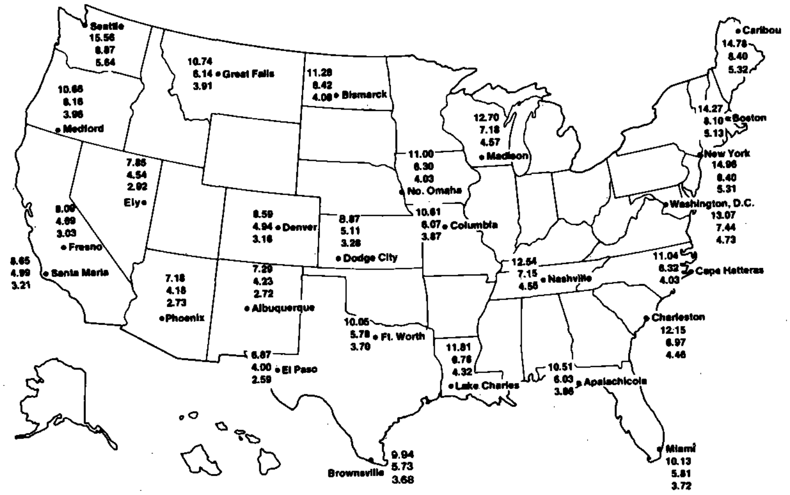

Figure 3. Required Fuel Price in 1979 Dollars/MBtu for a Ten Year Payback.
(Upper Number—1979 Startup; Middle Number—1985 Startup;
Bottom Number—1990 Startup)

PRELIMINARY CONCLUSIONS

Some general preliminary conclusions can be drawn from results of the discussions with trade associations, plant personnel during on-site visits, and results of the systems analysis.

- The availability of conventional fuels, such as natural gas, does not pose an immediate problem to any of the industries considered herein. Local utilities are actively promoting industrial uses of gas.
- The cost of energy is not a factor of significant importance to industrial users since, at some point in time, they are passed on in the distribution chain. However, payback period, which is an important industrial investment criterion when applied to solar energy systems, is directly dependent on the price of the displaced fuel.
- The inability of solar industrial process heat systems to meet normal industry payback period requirements (3-5 years) must be resolved if solar energy is to contribute significantly to U.S. industrial energy needs. Two areas of resolution are possible. First, efforts at system cost reduction and performance improvement must be continued. Second, industry may be motivated, through proper incentives or through increasing recognition of the severity of energy supply problems, to review the evaluation of conservation or solar applications under less restrictive economic criteria.

REFERENCES

1. Fraser, M. D. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat. ERDA/ITC No. 00028-1. Warrenton, VA: InterTechnology Corporation; 1977.
2. Hall, E. Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat. ERDA TID-27348/1. Columbus, OH: Battelle Columbus Laboratories.
3. Vickers, E. T.; et al. Energy Use in the Dairy Industry. NTIS-NP203050. Auckland, New Zealand: Energy Research and Development Committee; July 1979.
4. Knopf, F. C.; et al. Energy Utilization in a Dairy Processing Plant. Paper No. 78-6521. St. Joseph, MO: American Society of Agricultural Engineers; 1978.
5. Noyes Data Corp. Energy Saving Techniques in the Food Industry. Park Ridge, NJ: Noyes Data Corp.; 1977.
6. Drexel Univ. Energy Analysis of 108 Industrial Process, Preliminary Report. Philadelphia, PA: Drexel Univ.; June 1979.
7. Stadjuhar, S. A. An Applications Analysis for the Solar Industrial Process Heat Market. Tenth Annual Simulation and Modeling Conference; Pittsburg, PA; April 1979. SERI/TP-34-236. Golden, CO: Solar Energy Research Institute; 1979.
8. Dickinson, W. C.; Brown, K. C. Economic Analysis of Solar Industrial Process Heat Systems: A Methodology to Determine Annual Required Revenue and Internal Rate of Return. UCRL-52814. Livermore, CA: Lawrence Livermore Laboratory; August 1979.

SOLAR TRACKING SYSTEM
FOR LINE FOCUSING COLLECTORS

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Acurex Corporation has developed a sophisticated uniaxial tracking system with primary application to line focusing collectors for industrial process heat generation. The patented system consists of a solid-state logic module and sensor, as well as an innovative direct monitoring device. Emphasis was placed on performance, cost, durability, and compatibility with various types of drives and control systems. Tracking accuracies of better than ± 1/20 degree are typical. By using a special sensor device, cloud tracking was eliminated and labor-intensive installation was minimized. Design criteria and product information are presented in this paper. In addition, the internationally compatible signal interfaces and the priority setting control logic are described.

Objective

The objective of this project was to design, develop, manufacture, and install a "smart" tracking system for a line focusing collector that performs the following:

- Provide reliable tracking accuracy up to 1/16 degree rotation
- Discriminate between the sun and bright objects such as clouds
- Operate the field on days of adequate direct insolation only to minimize auxiliary power requirements
- Provide fail safe operation through design, and interface with system controls for overtemperature and no-flow protection

To date no other tracking system has proven reliability in performing all of these functions, which are required for reliable industrial process heat applications that use line focusing collector systems.

Project Description and Results

The Acurex Solar Tracking System increases the efficiency and reliability of concentrating single-axis tracking collector fields. It offers tracking accuracy up to 1/16 degree of rotation for maximum thermal or electrical output and uses solid-state control logic to offer a range of features unmatched by other trackers on the market.

The Acurex system combines three control elements in a unique package that can be operated easily with any single-axis tracking solar collector.

Commanding the collector field is a Direct Insolation Monitor (DIM). By monitoring direct insolation, the DIM automatically initiates tracking when sunlight is adequate for efficient operation of the solar system. On days of insufficient direct sunlight, the DIM stows the collectors. This minimizes parasitic power consumption and loss of stored energy.

The Acurex DIM uses microprocessor-based logic, and its sensitivity threshold can be adjusted to suit the operating requirements of any particular site and collector field.

Responding to the orders of the DIM, one Shadow-Band Sensor (SBS) at each collector drive motor tracks the sun when insolation levels warrant operation of the solar system. In a significant improvement over other trackers, the Acurex SBS discriminates between the sun and other bright objects, such as clouds or light-colored structures. This ensures that the sensor recognizes the sun as its target and prevents it from tracking spurious sources. The sensor maintains superior sensitivity on both clear days and smoggy, hazy, or overcast days.

Each Acurex shadow-band sensor is supplied with a Tracker Motor Control (TMC) to provide an easily connected interface with other system controls, including motor, over-travel limit switches, over-temperature sensors, no-flow pressure switches, and anemometers.

Together with the Shadow-Band Sensor, the TMC provides solid-state "negative" logic for fail-safe operation of collectors. The TMC accepts several customer inputs for operational and protective functions:

- Immediate 5° desteering based on fluid over-temperature
- Immediate stow on no-flow or reduced-flow condition
- Collector travel limiting in response to position switch signal
- Manual motor control for service or washing
- Automatic override of manual controls when collectors are inadvertently held on focus

With its accuracy and innovative package of features, the Acurex tracking system is helping users make efficient use of solar installations in industry.

System Features

- Discriminates between sun and clouds or other bright objects
- Automatically wakes system upon adequate direct sunlight
- No flow protection logic interface
- Over-temperature protection logic interface
- Rotational extreme operational logic interface
- Inadvertent operator action protection

Specifications

Accuracy

1/4 to 1/16 degree rotation

Power Consumption

- 15 watts w/motor off
- 375 watts w/motor on (duty cycle)

Voltage Supply

- 120V, 60 Hz
- 220V, 50 Hz
- Others on request

Control Signals

- Optical coupling
- Accepts ac or dc signals from 5 to 1500V

Enclosure Type

Weather-tight

Temperature

-40°C to 80°C

Relative Humidity

0 to 100% non-condensing inside NEMA 4 box

Data on System Performance

At present the Acurex tracking system has been delivered to three Acurex Solar Projects: Deep-Well Irrigation (Coolidge, Arizona); Johnson & Johnson IPH (Sherman, Texas) and U.S. Federal Credit Union for U.S. Steel (Crown Point, Indiana). Also, the Acurex tracking system has been installed and operating at the Acurex Solar Test Facility in Mountain View, California. This test park installation and the installation for Deep-Well Irrigation are the only projects to date that have begun or finished start-up. Experience at both of these installations has been excellent with tracking accuracy of 1/16 degree rotation.

SOLAR-INDUSTRIAL HEAT FOR NEW YORK STATE
A Case Study in Regional Impact on Economic Viability

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ABSTRACT

A study has been conducted to identify the economic potential for solar heat in the New York State processing industries, under the assumption of future escalation of fuel prices. In the course of this study it was necessary to identify the particular industries, their process-heat demands and their (regional) locations. New York State has been divided into two solar-performance regions: "Downstate", consisting mainly of the New York City Metropolitan area and "Upstate", the remaining rural and industrial areas. The climatology of these two regions is markedly different, with annual average insolation levels and ambient temperatures having a significant impact on solar performance in the low to intermediate range of industrial application temperatures (below 550°F). Of the six most energy-intensive processing industries (nationally), three only are promising for the State. The Primary Metals and Stone, Clay & Glass industries are eliminated from the solar applications, because over 96% of their processes are well above 500°F. The State has virtually no petroleum refining. This leaves only the Food & Kindred Products, Paper & Allied Products and Chemical industries to consider for solar in the State and of these the latter two are located primarily Upstate. Analysis has been carried out on each of these three industries, using the parameters of: heat demand, fuel type, application temperature, process-heat ratio, conventional-fuel system efficiencies and region to determine the state-wide economic potential market for 1985, using scenarios of (oil & nat. gas) fuel price escalations and level of government incentives. The regional effect is paramount in these results. Examples of individual manufacturing plants within each of the three industries have been studied, in order to verify some of the generic characteristics used in the analysis. This included site visits to the plants and discussions with company representatives in each case.

INTRODUCTION

New York State is located in the Northern Eastern region, which in the popular view is not likely for sites of large solar-array installations. More definitively, Upstate New York has been classified [1] along with northern New England in a solar-performance region that is the most difficult technically and economically in the country.

Nonetheless, in view of rapidly escalating fuel prices and concern for curtailments of fuel supplies in industry, no alternate energy sources

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and conservation measures should be overlooked for any region. With these policy motivations in mind, an assessment of the future economic potential for solar heat applications in the New York State processing industries was undertaken.

INDUSTRY ESSAYS

In order to assess the potential for solar heat applications in industry, it is necessary to essay each industry in sufficient detail that the substitution potential of solar heat, for heat derived from fuels, can be established. The essential parameters are [1-3]:

- The heat demands of each industry by fuel type, projected to a future year of interest.
- The fraction of purchased (and captive) heat used in each industry for process heat.
- The efficiency of utilization of each conventional fuel, in order to compare with solar heat delivered.
- The fraction of process heat utilized at each temperature, for each industry considered.
- The fuel price (also regional), projected for the future year of interest.
- The division of each of the industries by region, for solar collector performance.

For the New York State case, the projected fuel demands, for future, chosen years of interest, were obtained from recent studies [4,5] employing commonly accepted economic guidelines used for the nation as a whole [3]. The process-heat fractions, fuel efficiencies and temperature-utilization fractions were derived from the ITC study [1]. Regional (for N.Y. State) fuel prices were based on Federal Power Commission statistics [1] for historical prices, and projected [1,6] for future years of interest.

Finally, the solar-regional division of the industries within the State was done using data for purchased fuel, divided regionally by Upstate as versus Downstate categories for each (2-digit SIC) industry [7]. The Upstate vs Downstate division was chosen to correspond to the ITC [1] solar performance regions, which were utilized as the basis for the cost calculations described below. Out of 213 plants (state wide) in the three most promising industries, 176 are Upstate, with virtually all natural gas and oil demands in the Paper industry being Upstate and 99.7% and 97% for natural gas and oil Upstate in the Chemical industry, respectively. Only the food industry (SIC 20) has over half its natural gas demand (61%) Downstate, but 85% of its oil demand is Upstate. Coal and captive fuels were not analyzed in detail, since solar was not believed to be competitive with them within the time horizon (about 1995) of the study [8].

METHODOLOGY

The methodology of calculations for the New York State case follows closely that used previously by ITC [1] for the national case. Thus, a present-worth, life-cycle comparison is made of fuel costs versus the solar-system investment, assuming 100% backup by conventional-fuel systems. The marginal-cost technique permits an optimum-fraction solar division of the load demand to be determined for given parameters of (solar-performance) region, (process) application temperature and (projected) fuel price. These optimum fractions solar are then applied to the projected New York State fuel demands (principally natural gas and oil) of each (2 digit SIC) industry, as disaggregated by the temperature-utilization fractions mentioned above. This gives the annual process heat displaced (in TBTU/yr) for each fuel by such optimal use of solar. The re-aggregated sum over all application temperatures, for each industry, gives the potential, economic heat displacement of each fuel in each industry, state-wide, for the parameters assumed.

The ITC [1] dependence of solar-collector, marginal costs has been used as the base line of calculations. However, sensitivity calculations have been performed on these basis costs to reflect either: real (after inflation) changes in the (installed) costs of solar systems for industrial applications or the impact of government incentives. Similarly, real fuel escalation rates (above inflation) have been assumed for these calculations, again with sensitivity variations performed including the scenario used in the ITC study.

The calculations, as applied to the regional disaggregation of fuel demands for each industry, used the ITC [1] regional dependence of solar-collector (marginal) costs. Thus the solar costs used Upstate (corresponding to ITC Region I) reflected the higher costs of the larger collector areas required there as versus Downstate (ITC Region II).

RESULTS

Out of the five most energy-intensive process industries for the State, three only (food, paper and chemicals) have significant potential for solar heat applications, using proven, commercially-available solar technology. Two of the five industries (Primary Metals and Stone, Clay & Glass) have over 95% of their heat demands above 500^{o}F, which is above the "intermediate range" being considered for federal demonstrations. The potential of the remaining three is indicated in the figure.

Two features, regional and industry category, are salient in these results. The Upstate region quite obviously has the major potential for these industrial applications. This, of course, follows directly from the industrial geography and statistics given above. The three industries (SIC's 20, 26 and 28) are shown to be most responsive to incentives (portrayed as equivalent "% subsidy", to include federal, state and local programs). It should be noted, however, that these market potentials, with incentives, also assume real escalation of fuel prices in the range 5-10%. Finally, it is interesting to note that at the (equivalent) 50% subsidy level, solar heat is competitive for 56% of the (three-industry) heat demand Upstate and 78% competitive Downstate (mostly Foods), thus reflecting again the cost impact of regional solar

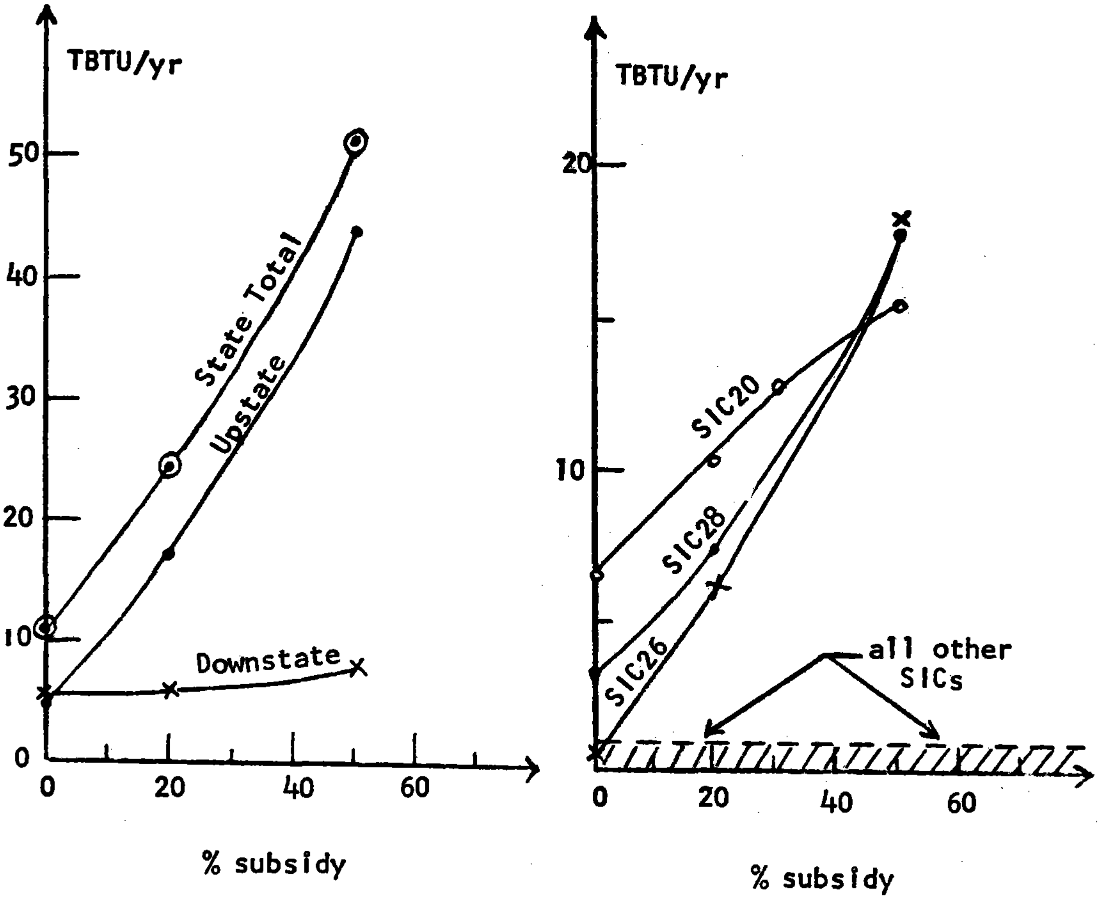

FIGURE - NEW YORK STATE PROCESS HEAT POTENTIAL
Process Heat Savings Versus Percent Subsidy Level
1985-90 Era

Legend
SIC20 = Food & Kindred Products
SIC26 = Paper & Allied Products
SIC28 = Chemical & Allied Products

TBTU = 10^{12}BTU

performance.

With a focus of interest on the State's three process industries, individual companies were surveyed as to their interest in solar heat applications. Site visits were made to a sample few who were receptive to consideration of future solar installations. The results of this survey showed some unexpected aspects for solar-industrial applications. Whereas the regional concentration (Upstate) of two of these most promising industries (Chemical and Paper) put particular burdens on solar performance and costs, more positive features were found, such as: the likely availability of land tracts for moderately-large collector fields and certain process applications (e.g. seasonal operations) which tended to compensate for the poor climatology of the region.

References

1. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, Vols. 1-3, Intertechnology Corp. Warrenton, VA. Report COO/2829, Feb. 1977.

2. Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat, Vols. 1-3, Battelle Columbus Laboratories, Columbus, OH, for USERDA, Report #T1D27348-1, Jan. 1977.

3. John G. Myers, et al., Energy Consumption in Manufacturing, The Conference Board, Ballinger Publishing Co., Cambridge, MA., 1974.

4. An Assessment of Energy Research, Development & Demonstration Priorities for N.Y. State, Interim Report, Vol. II, NCAES, Brookhaven Nat. Lab., Nov. 1977.

5. New York State Energy Analytic Information System - first stage implementation, NCAES, Brookhaven Nat. Lab., Oct. 1978.

6. Historic and Forecasted Energy Prices, Analysis Memorandum, DOE/EIA-0102/27, Dept. of Energy, Energy Info. Admin., Dec. 1978.

7. A proprietary data base of the Dept. of Energy & Environment, Brookhaven National Laboratory, Upton, N.Y., March 1979.

8. E.S. Cassedy, Solar Applications for Process Heat in New York Industry, Solar Energy Applications Center, Report: POLY-MAE #79-28, Polytechnic Institute of New York, Aug. 1979.

ECONOMIC VIABILITY OF THE SOLAR-ASSISTED INDUSTRIAL HEAT PUMP SYSTEM

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ABSTRACT

The U. S. Senate is currently considering a bill (S.1760) which would increase the tax credit allowed for solar industrial process heat (IPH) systems from the present 20%, up to 50% of the installed cost of such systems. This paper assesses the thermal performance and economics of solar-assisted industrial heat pump systems in typical IPH applications, as versus electricity, gas and oil, in three climate regions, under a present economic scenario, and under the scenario implicit in S.1760. TRNSYS Version 9.0 and SOLCOST Version 2.0 were employed to assess the 20-year life cycle economics of systems to identify the installation year(s) by which a system would yield a payback of less than 5 years and a return on investment of 25% or greater. It is concluded that the 30% additional solar IPH tax credit resulting from S.1760 would hasten the date of achieving economic viability by 4 to 5 years in most parts of the United States.

INTRODUCTION

Although there are some technical and institutional problems remaining, the principal barrier to the widespread use of solar energy in industrial processes continues to be economic. Recent studies have concluded that solar-assisted heat pump systems can demonstrate more attractive economics than solar-only systems in many applications [1,2]. In absolute terms, however, industry normally expects a payback of 5 years or less from capital invested in such a system. This appears to be a firm requirement and if a solar system cannot show the proper payback, it usually will not be built [3]. Additionally, in our experience, most industries require a 15% to 25% after-tax return on such investments (ROI).

As fuel prices continue to increase faster than inflation, the solar economic barriers will weaken. During the first half of 1979, natural gas prices rose at an annual rate of 22% and #2 fuel oil increased at a rate of 52%. With increasing pressure on the Government to decontrol oil and natural gas prices, and OPEC's continued powerful influence on our nation's oil supply, similar increases are likely in the years ahead. The impact on electric rates may not be as great as utilities shift back to the increased use of coal and take steps to improve electrical load factors. These trends tend to hasten the date of solar economic viability as versus fossil fuels.

As importantly, the U.S. Senate is currently considering a bill (S.1760) which would increase the current 20% solar tax credit for IPH systems, up to a total of 50%. All of these forces impact upon solar economic viability, and this paper attempts an assessment of the results of that impact.

THE SOLAR-ASSISTED-TEMPLIFIER^R HEAT PUMP SYSTEM

The concept of a solar-assisted heat pump system is based on the recognition that it is significantly more efficient and cost-effective to collect solar energy at lower temperatures, ranging from about 40°F to 140°F, and then boost it to the required load temperature with an industrial heat pump. Before assessing the performance and economics of such systems in specific applications and economic scenarios, a review of the principle characteristics of such systems is in order.

It is a characteristic of *all* solar collectors that, the lower the collector operating temperature, the greater the amount of available solar energy produced by that collector. That's why solar systems used simply to preheat cold feed water (CFW) are the first to become economically attractive, both in the residential (DHW) and industrial (boiler feedwater) arenas. Consider the typical flat plate collector curve in Figure 1.

Fix insolation (I) and ambient air temperature (T_A) at, say, 250 BTU-H/FT^2 and 50°F respectively. Now, *the cooler the collector is operated, the more efficiently it produces solar energy*.. the smaller the collector area required to produce the same number of solar BTU. And CFW is usually the coolest liquid temperature encountered in an industrial process heat cycle.

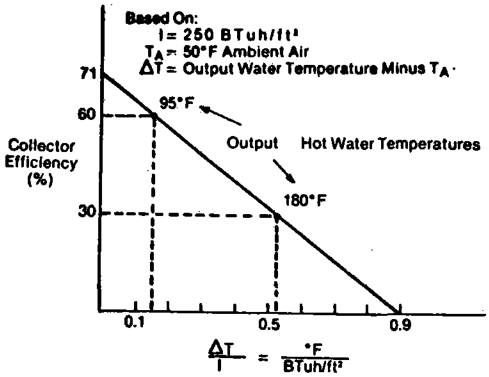

Figure 1. Collector Efficiency Curve

Many industrial processes require little cold feedwater preheat, but expend most of their heat energy in maintaining a high temperature bath in a closed-loop cycle. It has been shown that, in many such processes, *a solar-assisted heat pump system can deliver more useful solar energy to a high temperature load at a lower cost, than can a solar-only system* [1].

One such industrial heat pump, the Westinghouse Templifier^R, can deliver process hot water in a closed-loop cycle at temperatures from 110°F to 220°F, at rates of 150 MBH to 10 MMBH, while operating from solar source storage temperatures of 50° to 130°F. Here, the solar portion of a Solar-Assisted-Templifier (S-A-T) system is operating efficiently at low temperature, while the Templifier heat pump is producing the heat required at the load. A comparison of an S-A-T system and a solar-only system in this application is shown in Figure 2. Note also in this example that any recoverable process waste heat at or above 95°F can be input into S-A-T storage as an additional free heat source to the heat pump.

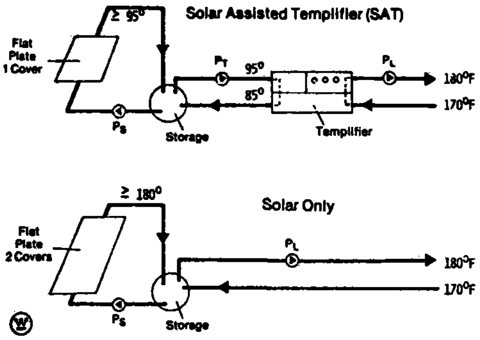

Figure 2. Systems Comparison

In order to lift warm solar water up to the temperature required at the load, the heat pump compressor requires an additional input of electricity. However, some 92% to 94% of this electricity also goes to useful heat output to the load.

Figure 3 shows the Coefficient of Performance (COP) of the Templifier heat pump. As an example, 95°F solar warm water entering the heat pump would be cooled to 85°F, returning to solar storage where it is again heated by the solar collectors to 95°F. The solar energy given up to the heat pump can be pumped up to a 180°F outlet temperature at a COP of about 3.0. That is, for every unit of electric energy used, the heat pump delivers 3.0 units of energy to the load. The remaining two units of energy, of course, are drawn from stored solar and/or waste heat energy.

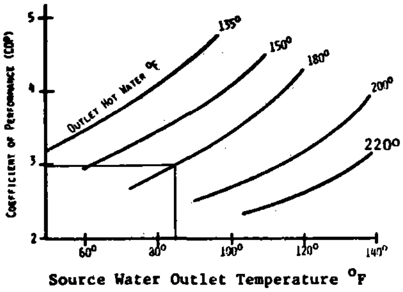

Figure 3. Templifier COP

A final point to be made regarding solar-assisted industrial heat pump systems concerns solar collector costs and efficiency. As the heat pump pulls heat from solar storage, the storage tank (and the solar collector inlet temperature are maintained at a low, design point temperature. This results in a collector fluid parameter (ΔT/I) on the order of 0.1 to 0.15. This solar operating regime allows consideration of lower performance and lower cost solar collectors.

Figure 4 shows performance curves for various solar collector panels. Note that at low ΔT/I, the source regime of the industrial heat pump, the lowest cost collector performs more efficiently than the highest cost collectors. As a result, this low-cost, glazed "swimming pool" type collector is being recommended for industrial S-A-T systems in climate regions of less than 5,000 heating Degree-Days.

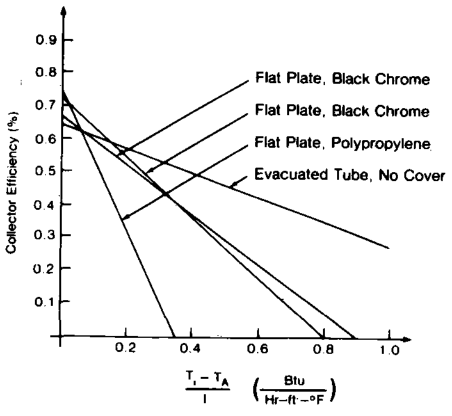

Figure 4. Various Collector Performance Curves

ECONOMIC ANALYSES

Present Scenario

It has been shown that a Solar-Assisted-Templifier (S-A-T) heat pump system, in producing hot water below 220°F to year 'round industrial process loads, can be installed at about $79 to $161 per million solar BTU delivered annually. Under the same conditions, a solar-only system cost $145 to $336 per million solar BTU delivered [1]. The study determined that the S-A-T system could payback in less than 10 years with an ROI greater than 8% against electricity today in almost every region of the country. Against gas or oil, the S-A-T system would payback at 6% to 8% in 12 to 13 years in the sunbelt region. *These economics could not be matched by solar-only systems.*

Five Year Payback, 25% ROI After Taxes

To determine the S-A-T system installation dates and conditions which might interest industrial plant owners, the authors have conducted extensive analyses using the TRNSYS Version 9.0 and SOLCOST Version 2.0 computer programs. Installed solar system and heat pump costs were based upon the installation labor and materials costs for similar, operating systems. Costs of such variables as design engineering, project management, monitoring instrumentation, etc., were not included. These and other assumptions are listed in the Appendix.

Applying 20% and 50% solar tax credits to the assumptions listed in the Appendix, computer iterations were performed to determine *in what year(s) might an S-A-T IPH system be installed with reasonable expectation of a payback in less than five years and an ROI of greater than 25% over a 20-year life-cycle.* The results are shown in Table 1.

TABLE 1. S-A-T INSTALLATION YEAR WITH EXPECTATION OF PAYBACK <5 YEARS AND ROI >25%

Alternate Fuel	Electricity	Gas	Oil
Site/Scenario			
Albuquerque, NM			
50% Tax Credit	1979-80	1984-86	1984-86
20% Tax Credit	1984-86	1988-90	1989-90
Charleston, SC			
50% Tax Credit	1979-80	1982-84	1983-85
20% Tax Credit	1984-86	1986-88	1988-90
Madison, WI			
50% Tax Credit	1983-85	1987-89	1989-90
20% Tax Credit	1990+	1990+	1990+

CONCLUSIONS

The expected dates of the S-A-T IPH economic viability against conventional fuels, when measured against very stringent payback and ROI requirements under the assumed scenarios, are evident in Table 1 above.

The allowance of a 50% solar IPH tax credit, in lieu of the 20% credit presently allowed, would hasten the date of achieving economic viability by 4 to 5 years in most areas of the United States.

REFERENCES

1. A. Weinstein & G. J. Van Zuiden, "Reducing Solar Costs With the Solar-Assisted-Templifier", ISES 1979 International Congress Proceedings, (1979), P. 231.

2. T. L. Freeman, J. W. Mitchell & T. E. Audit, "Performance of Combined Solar-Heat Pump Systems", Solar Energy, Vol 22, No. 2, (1979), P.125-135.

3. A. B. Casamajor & R. L. Wood, "Limiting Factors for the Near-Term Potential of Solar Industrial Process Heat", Solar Industrial Process Heat Conference Proceedings, Vol. 1, (1979), P.175-185.

APPENDIX
ANALYSIS ASSUMPTIONS

Industrial Regions	Albuquerque,NM; Charleston,SC;Madison,WI
Industrial Loads	150^{0}, 575-585 MBH, 480 Hrs/Mo
Solar Fraction of Load	$\sim$50%
Owner's Tax Bracket	48%
Financing	100% Down Payment
Fuel Prices	Local Industrial Rates
Fuel Price Escalation	
Gas	20%
Oil	14%
Electricity	10%
General Inflation Rate	7%
Investment Tax Credit	20%, 50%
* Solar System, Installed	
Polypropylene	\$25/ft^2 (NSF-410 Collector)
1-Cover, Black Chrome	\$41/ft^2 (NSR-132 Collector)
* Heat Pump, Installed	\$28,500 (Templifier)
As a % of Installed Cost,	
Maintenance/Year	1.0%
Insurance/Year	0.5%
Depreciation for Taxes	10 years, D.B@1.5
System Life	20 Years
Salvage Value	0.0
CRITERIA	Payback <5 Years, ROI >25%

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* Escallated at 6% per year

SOLAR PONDS FOR INDUSTRIAL PROCESS HEAT

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ABSTRACT

Solar ponds offer perhaps the simplest technique for conversion of solar energy to thermal energy, which can be used for industrial process heat. It is unique in its capability in acting both as collector and storage. Further, the cost of solar pond per unit area is less than any active collectors available today. Combination of these economic and technical factors make solar ponds attractive as a fuel saver in IPH applications. This paper presents detailed calculation of solar ponds in two specific applications: providing hot water for aluminum can washing in a manufacturing plant and hot water for washing in a large commercial laundry. With the help of computer codes developed at SERI for other solar IPH systems, it is shown that solar ponds are far more cost effective than any other solar IPH technology for these applications.

INTRODUCTION

The solar pond is probably the simplest technique for direct thermal conversion of solar energy. It is simultaneously a collector of solar radiation and a large body of thermal storage. Any pond converts insolation to heat, but most natural ponds quickly lose that heat through vertical convection within the pond and evaporation and convection at the surface. The solar pond artificially prevents vertical convection, surface evaporation and convection, or both. Because of its massive thermal storage and of measures taken to retard heat loss, the typical pond takes weeks for a 10° C temperature loss, even in the absence of insolation. Thus, the solar pond converts an intermittent energy source—solar radiation—into a reliable source of thermal energy.

The best established variety of solar pond is the salt gradient solar pond. The salt gradient solar pond has been studied since the early 1960s in Israel [1-3], and one has now been operating in a commercial application for over a year at Miamisburg, Ohio [4]. The salt gradient solar pond contains a "nonconvective layer" of about a meter in thickness in which salt is dissolved in concentrations that increase with depth. Hence, the increased weight of the lower pond depths prevents thermal buoyancy convection.

The heated water does not rise, thus heat loss is retarded. Salt gradient solar ponds can achieve temperatures up to the boiling point of the salt solution.

The salt gradient solar pond is commercially ready to aid in meeting many industrial process heat (IPH) requirements. Solar ponds are useful for preheating even in applications where the end use temperature exceeds the typical solar pond temperature. Only about 2.5% of IPH energy in the United States is required at an end use temperature less than 70° C. When preheating to 70° C is considered, 19% of U.S. IPH energy requirements fall within the scope of solar ponds [5]. However, some critical environmental and technical issues need to be resolved before solar ponds can be widely implemented.

APPLICATIONS SELECTED

To assess the feasibility of solar pond technology for IPH applications and compare the suitability of ponds with more conventional solar technology, two industrial applications as reported in the Solar Energy Research Institute's (SERI) case studies [6,7] were selected for analysis. Through the SERI industrial case study program, complete energy audits of industrial plants are performed and used to provide the basis for solar system sizing and performance analysis. The result is a report on solar system size, performance, cost and life-cycle cost in a number of possible configurations that may include conservation and process redesign. Case studies performed since 1978 include those of a luggage manufacturing plant, commercial laundry, metal container manufacturer, bakery, dairy, paint resin plant, wet corn-milling operation, and an oil recovery operation. Solar systems that have been analyzed include hot air, hot water, and steam systems using flat plate, evacuated tube, Fresnel lens, and parabolic trough collectors. However, the studies did not include appropriate solar pond technology. This paper builds upon the significant achievements of the case study program and presents a comparative analysis of two low temperature hot water applications.

One application focuses upon the hot water requirements for aluminum can washing in a Colo. manufacturing plant where cans are shaped and trimmed from sheet stock, then washed and dried before being sent for bottom coating and printing. On the average, the can processing lines operate 24 h per day, 6.5 days per week, and 50 weeks during the year. Most of the energy used in the plant (supplied by natural gas at \$1.93/GJ) is required for can drying. However, approximately 22% of the total energy input goes to a water heater that supplies 60° C (140° F) water to the can washer. Water is heated via steam. The total annual energy requirement for can washing on one process line is 2.3×10^{12} joules (2,185 MBtu).

The second application is for hot water used in washing in a large Colo. commercial laundry. Water is heated via steam and effluent heat exchangers. Steam is primarily used in the ironing machines (the largest load in the plant) so that it is conceivable that the required hot water at 82° C (180° F) could be alternatively supplied directly by a solar system. The hot water load constitutes only 8% of the total plant energy demand. The laundry normally operates for one daytime shift, 8 h each day, 6 days per week. Total annual energy to be supplied is 4.3×10^{12} joules (4,085 MBtu). Energy is supplied via natural gas at $1.85/GJ.

DESIGN OF SOLAR POND IPH SYSTEMS

Solar pond systems were sized to assist the IPH needs of the metal can manufacturer and the commercial laundry. Some salient features involved in solar pond sizing for IPH applications are mentioned here. Details of sizing and performance prediction are given in Refs. 4 and 5. The larger the pond surface area compared to the load, the higher the temperature of the output will be. The deeper the pond, the less the temperature will fluctuate seasonally. In theory, a pond could have been sized to provide 82° C continuous output, as required for the commercial laundry. The incremental surface area and depth required, however, to increase the pond's minimum output temperature from 80° C to 82° C is considerably greater than that required to increase it from 60° C to 62° C. Therefore, there is likely to be an optimal size at which the marginal cost of increasing the pond's area is equal to the cost of backup energy. Hence, the optimal solar pond may use backup, even though it may be feasible to size a solar pond large enough to require no backup.

For the metal can washing application, a solar pond was sized to achieve an annual average temperature of 55° C, with an annual high of 65° C, and an annual low of 45° C. It was assumed that a 5° C loss would be suffered in exchanging heat from the pond. Hence, at its peak temperature of 65° C, the pond will just satisfy without backup the application's requirement for 60° C water. At all other times, it will require backup to boost the temperature. The pond is 5143 m^2 (1.27 acres) in surface area and 4.9 m deep. The capital cost of the pond alone is $128,000 if salt is free, $173,000 if salt costs $10 per ton, and $218,000 if salt costs $20 per ton. The costs of the heat exchanger and piping were conservatively assumed to be $8/$m^2$ of pond surface area.

For the laundry application, a solar pond was sized to achieve an annual average temperature of 65° C, with an annual high of 80° C, and an annual low of 50° C. This pond is 3552 m^2 (0.88 acre) in surface area and 3.2 m deep. Its capital cost is $76,000 with free salt, $94,000 at a salt cost of $10/ton, and $112,000 at a salt cost of $20/ton. Again, heat exchanger and piping costs were assumed to be $8/$m^2$.

COMPARISONS WITH "CONVENTIONAL" SOLAR

The simulation codes PROSYS and ECONMAT [6] were used in SERI case studies of the two applications to assess annual performance and costs of alternative "conventional" solar IPH systems. Approximately 20 different collectors were analyzed and the most cost effective collector and system were chosen for each application. Table A shows the cost and performance characteristics of each conventional solar system and of the comparable solar pond system for three assumed salt costs. The annual energy outputs of the solar ponds for the two applications were calculated using the method described in Ref. 8. Note that the configured systems will annually deliver different amounts of energy. A comparison is possible, therefore, only on the basis of annualized energy costs or projected rates of return. It is useful, however, to compare the relative amounts of capital investment required for unit annual energy delivery. The capital capacity cost of the conventional

Table A. COMPARATIVE COST AND PERFORMANCE OF CONVENTIONAL SOLAR SYSTEMS VERSUS A SOLAR POND SYSTEM

System Type	Area Land Required	Annual Energy Delivered	Collector Subsystem Cost	Balance of Plant[a]	Total Capital Cost	Estimated Annual OMPI
Metal Can Washing						
Parabolic Trough Collector Heat Exchange System	1275 m^2 (13,695 ft^2)	2.3×10^{12} J (2,200 MBtu)	$193,000	$197,000	$390,000	$ 7,500
Salt Gradient Pond at $20/Ton For Salt	5143 m^2 (55,339 ft^2)	5.6×10^{12} J (5,320 MBtu)	$218,000	$196,600	$414,600	$ 8,000
Salt Gradient Pond at $10/Ton For Salt	5143 m^2 (55,339 ft^2)	5.6×10^{12} J (5,320 MBtu)	$173,000	$196,600	$369,600	$ 8,000
Salt Gradient Pond at 0/Ton For Salt	5143 m^2 (55,339 ft^2)	5.6×10^{12} J (5,320 MBtu)	$128,000	$196,600	$324,600	$ 4,000

Laundry Hot Water

System Type	Area Required	Annual Energy Delivered	Collector Subsystem Cost	Balance of Plant[a]	Total Capital Cost	Estimated Annual OMPI
Parabolic Trough Collector, Heat Exchange System	2087 m^2 (22,450 ft^2)	2.96×10^{12} J (3,750 MBtu)	$313,000	$319,800	$632,800	$13,300
Salt Gradient Pond at $20/Ton For Salt	3552 m^2 (38,220 ft^2)	3.06×10^{12} J (2,907 MBtu)	$112,000	$112,700	$224,700	$ 4,500
Salt Gradient Pond at $10/Ton For Salt	3552 m^2 (38,220 ft^2)	3.06×10^{12} J (2,907 MBtu)	$ 94,000	$112,700	$206,700	$ 3,700
Salt Gradient Pond at $0/Ton For Salt	3552 m^2 (38,220 ft^2)	3.06×10^{12} J (2,907 MBtu)	$ 76,000	$112,700	$188,700	$ 3,500

[a] Includes materials and labor for installation of auxiliary equipment items, such as heat exchangers, plus 60% of direct field costs for indirects, contingency, and fee.

systems (total capital cost divided by annual energy delivered) is approximately $165 per GJ/yr ($173/MBtu/yr). The capital capacity costs of solar pond IPH systems vary between $74 per GJ/yr for expensive salt and $60 per GJ/yr for free salt ($77/MBtu/yr to $62/MBtu/yr). However, approximately twice as much land area is required for the pond as for the conventional trough collectors to deliver the same annual energy.

Installation of a retrofit solar IPH system (no storage is assumed for these systems and full conventional backup is available) is a "service" investment whose costs are offset by savings accrued from reduced fuel consumption. To compare the economic viability of the parabolic trough with the solar pond, a rate of return calculation was performed for each application using the method identified in Dickinson [10].

Equity financing was assumed, with a 20-yr service life, 7-yr depreciation, 50% tax rate, and 20% investment tax credit. No salvage value was taken. Therefore, a multiplier may be determined for various rates of return and the levelized cost of solar energy plotted against rate of return. On the same graph, the levelized cost of the fuel displaced may be plotted for various discount rates. The rate of return from the given project is then found at the intersection of the two curves. Figure 1 shows the rate of return calculation for the metal can washing application and the calculation for the commercial laundry. Two levelized fuel prices are assumed in each case: (1) current quoted price of fuel with an 8% rate of escalation and (2) fuel price of $5.00/GJ ($5.27/MBtu) escalating at 10% per annum. An efficiency of conversion to delivered heat of 85% in metal can washing and 75% in the laundry is assumed.

As can be seen in the charts, installation of any sort of solar IPH system in either application does not offer adequate return on investment when compared to costs of natural gas and a fuel price escalation rate of 8%. However, when compared to natural gas at $5.00/GJ escalating at 10%, the solar pond

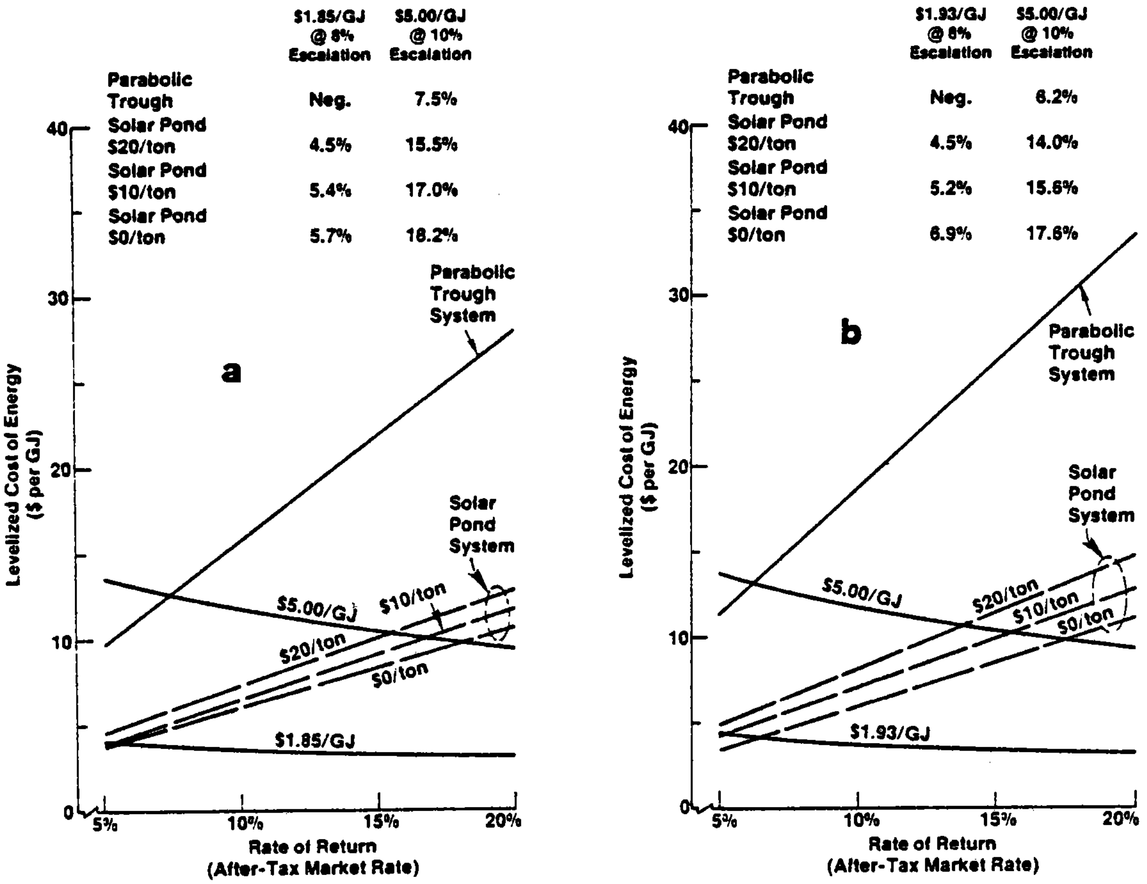

Figure 1. EXAMPLE OF A RATE-OF-RETURN CALCULATION FOR (a) A METAL CAN WASHING PROCESS AND (b) A COMMERCIAL LAUNDRY PROCESS

systems usually provide a rate of return in excess of 15%, which is generally sufficient to warrant commitment of funds in general service investments. The alternative conventional parabolic trough systems offer less than half of this rate for the same fuel price scenario. Hence, solar ponds justify serious consideration as economic alternatives for low temperature IPH. In addition, it appears that the return from solar pond systems is not highly sensitive to salt cost.

CONCLUSIONS

In conclusion, salt gradient solar ponds achieve economic viability as a fuel saver in IPH applications when fossil fuel prices are $5/GJ and are expected to increase 10% per annum. Although the cost of salt for ponds varies widely with location, it does not appear to affect overwhelmingly the pond's economic feasibility. Solar ponds are useful as preheaters for intermediate and high temperature IPH applications as well as for low temperature applications. They are often more economically used as preheaters even when the end use temperature is so low that a large solar pond alone could suffice. For the applications studied in this paper, solar ponds appear to be far more cost effective than any other solar IPH technology. Their economic attractiveness, as well as their simplicity, should make solar ponds a subject for increasing study and experimentation in IPH applications.

ACKNOWLEDGEMENTS

The authors are indebted to the SERI Industrial Case Study program, particularly Mr. D. W. Hooker and Dr. R. E. West, for input data on the industrial applications selected for this analysis. Their reports supplied the general descriptions and load characteristics for the processess given here and also the cost and performance characteristics of the compared conventional systems.

REFERENCES

1. Tabor, H. "Solar Ponds: Large Area Collectors for Power Production." Solar Energy 7 (No. 4, 1963): pp. 189-194.
2. Tabor, H.; Matz, R. "A Status Report on Solar Pond Projects." Solar Energy 9 (No. 4, 1965): pp. 177-182.
3. Weinberger, H. "The Physics of the Solar Pond". Solar Energy 8 (No. 2, 1964): pp. 45-56.
4. Wittenberg, L. J.; Harris, M. J. "Performance of a Large Salt-Gradient Solar Pond." Proceedings of the 14th Intersociety Energy Conversion Engineering Conference; Boston, MA; 1979; pp. 49-52.
5. InterTechnology Corporation. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat. 1 (February 7, 1977): p. 53.
6. Brown, K. C.; et al. End-Use Matching for Solar Industrial Process Heat. Golden, CO: Solar Energy Research Institute; October, 1979. SERI/TR-34-091.
7. Hooker, D. W.; West, R. E. Industrial Process Heat Case Studies. Golden, CO: Solar Energy Research Institute; SERI/TR-34-323. Forthcoming.
8. Edesess, M.; Henderson, J.; Jayadev, T. S. A Simple Design Tool for Sizing Solar Ponds. Golden, CO: Solar Energy Research Institute; SERI/RR-351-347. Forthcoming.
9. Jayadev, T. S.; Henderson, J. "Salt Concentration Gradient Solar Ponds." Modeling and Optimization Proceedings of 1979 ISES Conference; Altanta, GA; May 28, 1979.
10. Dickinson, W. C.; Brown, K. C. Economic Analysis of Solar Industrial Process Heat Systems. UCRL-52814. Livermore, CA: Lawrence Livermore Laboratory; August 17, 1979.

TWO CASE STUDIES OF THE APPLICATION OF SOLAR ENERGY FOR INDUSTRIAL PROCESS HEAT

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ABSTRACT

Case studies of industrial process heat (IPH) have been performed by the Solar Energy Research Institute (SERI) on selected plants in metal processing, oil production, beverage container manufacturing, commercial laundering, paint (resin manufacturing), and food industries.

For each plant, the application of solar energy to processes requiring hot water, hot air, or steam was examined, after energy conservation measures were included. A life-cycle economic analysis was performed for the solar system compared to the conventional energy system. The studies of the oil production facility (oil/water separation process) indicate that it could economically employ a solar hot water system immediately. The studies of solar energy applied to the beverage container process (solar air preheat system with partial recycle of oven exhaust gases) indicate a 7.5-yr payback period, based on a solar system installation in 1985.

INTRODUCTION

Industry consumes about 36%-37% of the U.S. gross energy demand. Fifty to seventy percent of this demand is for industrial process heat (IPH) - the thermal energy used in the preparation and treatment of manufactured goods [1]. Since approximately 27% of the total IPH requirement is at temperatures below 288°C (550°F) [1], commercially available solar collectors could potentially be applied to this large market.

SERI is performing IPH case studies which include solar applications analyses for individual plants. The objectives of the program are: 1) to determine the near-term feasibility of solar IPH in selected industries; 2) to identify energy conservation measures and energy-saving process modifications; 3) to test SERI's solar IPH analysis software (PROSYS/ECONMAT) [2] and discover improvements; 4) to identify conditions of IPH systems affecting the potential use of solar energy; and 5) to disseminate information to the industrial community about solar IPH applications.

Solar IPH case studies were performed using PROSYS/ECONMAT for plants in several industries. A site visit and plant tour were first conducted. Then, during meetings between SERI and the plant staff, processes were chosen for study and data for heat and mass balances were gathered. Energy conservation and process reconfiguration measures (if any) were identified, solar systems designed by SERI were sized and priced, and economic analyses were conducted using PROSYS/ECONMAT. The results were then submitted to the plant staff for approval.

RESULTS

Two case studies of a crude-oil/water separation facility and an aluminum beverage container manufacturing plant are discussed in this paper. (Reference 3 documents all case studies of 1978.)

Oil/Water Separator

A case study was performed of a crude-oil/water separation facility (heater-treater) in Wyoming. The facility operates 24 h/d, 7 d/wk, year-round. A schematic of the separation process is shown in Fig. 1. The emulsion of crude oil and water, in a ratio of about 59 to 1 by volume, enters the separator tank at 27°C (80°F) from a nearby oil well at a rate of 329 kg/h (725 lb/h). The emulsion is heated in the separator tank to 57°C (135°F) by a propane burner system at a heat rate of about 2.1 x 10^7 J/h (2.0 x 10^4 Btu/h); this corresponds to an annual energy use of 1.85 x 10^{11} J (1.75 x 10^8 Btu). At 57°C the crude oil and water separate. The less-dense crude oil floats to the top of the tank, where it is drained off, and the water is drained from the bottom of the tank.

Many larger oil wells produce natural gas, which is used as the fuel for the separators. Small wells, such as the one under consideration, produce little or no gas; propane is the sole fuel for the separator under study. As of March 1979, the firm was purchasing propane at 14¢/l (52¢/gal.), which is equivalent to \$5.33/GJ (\$5.62/10^6 Btu). Approximately 5190 l/mo (1370 gal./mo) of propane are used by the separator, resulting in an annual propane energy input of 1.57 x 10^{12}J(1.49 x 10^9 Btu). Since 1.85 x 10^{11} J/yr (1.75 x 10^8 Btu/yr) are required for heating the crude-oil/water emulsion, the net energy utilization efficiency is about 11.7%.

The low efficiency results from the design of the separator tank; this design has little potential for additional energy savings. Additional insulation could be added to the tank to reduce the losses [estimated to be 3.6 x 10^6 J/h (3.4 x 10^3 Btu/h) at -17.8°C (0°F)], but an insignificant amount of energy would be saved compared to the amount lost in the burner exhaust gases. Insufficient information was available to estimate how much of the burner exhaust gases, if any, could be recycled to the burner to reduce the propane usage.

The computer codes PROSYS/ECONMAT were used to analyze applications of solar energy for heating the separator tank. Three systems were examined: 1) an oil-through-collector system in which the crude-oil/water emulsion is sent from the well directly to the collector field, heated to the process temperature, and then sent to the separator tank; 2) an external heat exchange system in which the crude-oil/water emulsion is heated to the process temperature before entering the separator tank via heat exchange with a closed-loop liquid collector system; and 3) an in-tank exchange system in which the crude-oil/water emulsion is sent to the separator tank from the oil well and is heated to the process temperature by a closed-loop liquid collector system via a heat exchanger inside the separator tank.

The external exchange system shown in Fig. 2 is preferred because it avoids, for example, the necessity for system draindown each evening or modification of the separator tank assembly. The PROSYS simulation for this system indicates that 18.0 m^2 (193 ft^2) of a commercially available parabolic trough collector is the most cost-effective solar system. The parabolic trough collector is preferrable to a flat-plate collector because of the increased average collector temperature in the external exchange system (58°C, 137°F) as compared to the oil-through-collector system (47°C, 117°F): the thermal efficiency of the parabolic trough is higher than a flat plate at the increased operating temperature.

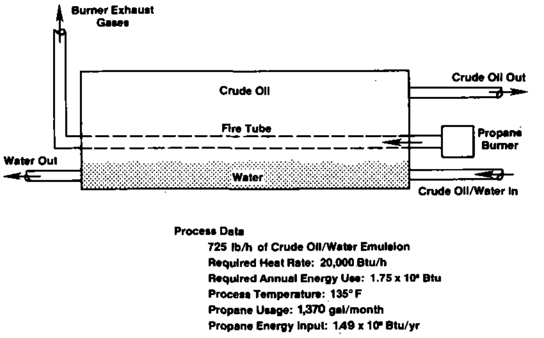


FIG. 1. CRUDE OIL/H_2O SEPARATOR TANK

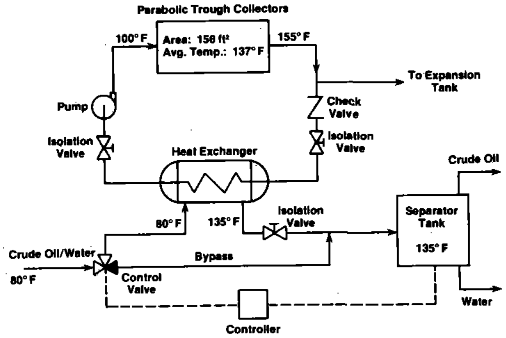


FIG. 2. CRUDE OIL/WATER SEPARATION FACILITY: EXTERNAL HEAT EXCHANGE SYSTEM

The external heat exchange system was sized to displace about one-third of the process energy requirement during a typical year (6.8 x 10^{10} J or 6.4 x 10^7 Btu). The solar system displaces 5.8 x 10^{11} J (5.5 x 10^8 Btu) of propane energy because of the low propane utilization efficiency.

The parabolic trough collectors used in the simulation of the external exchange system cost a total of $5900 in 1979. The remainder of the system costs are estimated to be $6800 [4,5,6], resulting in a total installed cost of $12,700. The life-cycle cost analysis, using ECONMAT, shows that the external exchange system has a positive net present value of $35,600 (assuming a 20-year solar system lifetime) when compared to the conventional propane system. Thus, the solar system is competitive with the propane system (which is expensive and inefficient) and has a payback period of less than 3.4 yr for a 1979 startup. Table 1 summarizes the solar system parameters.

Aluminum Beverage Can Manufacturing

An IPH case study was done of an aluminum can manufacturing line in Colorado. The process consists of shaping and trimming the can bodies, followed

Table 1. SOLAR SYSTEM PARAMETERS

Parameter	Crude Oil/Water Separator	Aluminum Can Manufacture
Collector	parabolic trough	parabolic trough
Collector area (m^2)	18.0	274
Process temperature (°C)	57	87
Average annual solar energy supplied (J)	6.8×10^{10}	1.7×10^{12}
Average annual energy displaced (J)	5.8×10^{11}	5.9×10^{12}
Collector cost (1979\$)	5,900	140,000
Total system cost (1979\$)	12,700	152,000
Net present worth (1979\$)	35,600	27,000
Capacity cost (1979\$/GJ/yr)	178	91
Delivered energy cost (1979\$/GJ)	20	10
Payback period (yr)		
1979 startup	3.4	16.1
1985 startup	2.2	7.5

by washing and drying. The cans are printed and bottom coated, passed through a direct-fired oven to cure the ink and coating, and cooled. They are then coated internally, cured in a direct-fired oven, cooled, necked, pressure tested, and palletized.

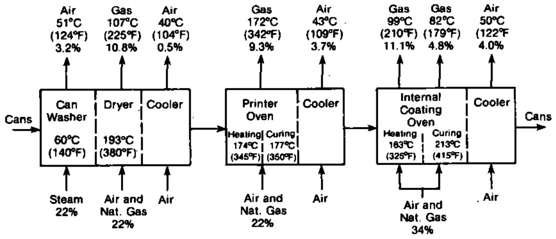
Process heat is supplied to heat the wash water, dry the cans after washing (direct-fired), and heat the printer oven and internal coater oven (see Fig. 3). The plant operating schedule is 7 d/wk, 24 h/d, year-round. With shutdowns, the average operating time is 24 h/d, 6.5 d/wk, 50 wk/yr.

Figure 3 summarizes the results of the energy balances and shows that some 48% of the estimated total energy input to the process of 4 GJ/h (3.8×10^6 Btu/h) leaves in the exit hot gases. The remainder leaves as heat of vaporization of water, heat losses to the building air, and sensible heat of the cans and can conveyor. The fuel currently used is natural gas at \$1.93/GJ (\$2.04/10^6 Btu) of heating value (Dec. 1978 price).

An energy conservation analysis indicated potential for substantial energy recovery in the dryer, ovens, and coolers in the form of the sensible heat of the exhaust gases. One means of recovery would be heat transfer between the exhaust gases and incoming air, but, since it is gas-to-air exchange, relatively large heat exchangers would be required. The most direct recovery of this energy would be to reuse the gases. Whether or not a solar system is employed, the air used to cool the cans should be used as a preheated air supply to the gas burners, saving 8.2% of the total IPH requirement. Some of the hot combustion product gases might be recycled. These alternatives were considered in the solar applications analysis.

The application of solar energy to can manufacture was examined in three ways: 1) by using solar collectors to supply one-third of the total annual energy required for the dryer and ovens (i.e., 1/3 of 22 TJ/yr) via hot air at the maximum required process temperature of 213°C (415°F); 2) by employing individual collectors to supply energy via hot air or water to each unit at the maximum temperature required; and 3) by applying a reconfigured process air flow for make-up air preheating in the coolers and by recycling a portion of the hot exhaust gases (solar energy further preheating the make-up air). Solar energy is not competitive with efficiently used natural gas if the solar system supplies the same amount of energy as that supplied by the displaced natural gas [conditions (1) and (2)]. However, when solar energy is used together with air preheating and partial recycle of hot off-gases, one solar system has a 7.5-yr payback with a 1985 system startup (see Table 1). This design recycles the hottest half of the off-gas streams, using the can coolers to preheat incoming air and employing solar collectors to further preheat this air.

Figure 4 presents the final air flow configuration. In this configuration, incoming air passes through the can coolers. The hottest air, that from the internal-coating oven can cooler and about one-third of that from the print oven can cooler, is circulated to solar collectors where it is heated to 87°C (189°F). The off-gas from the print oven and the can washer/dryer, and about two-thirds of the off-gas from the internal-coating-oven heat section are mixed with the solar preheated air. This mixed gas stream is then used as preheated combustion air for the gas-fired units: the can washer/dryer, the print oven, and the internal-coating oven.



- Estimated Total Energy Input 4 GJ/h
- Percentages are Sensible Heat in Gas (Relative to 31°C, 88°F) as % of Total Energy Input
- Sensible Heat of Off-Gases Accounts for 48% of Energy Input. Balance is Due to Water Evaporation and Heat Losses

FIG. 3. METAL CONTAINER PROCESS ENERGY FLOW DIAGRAM

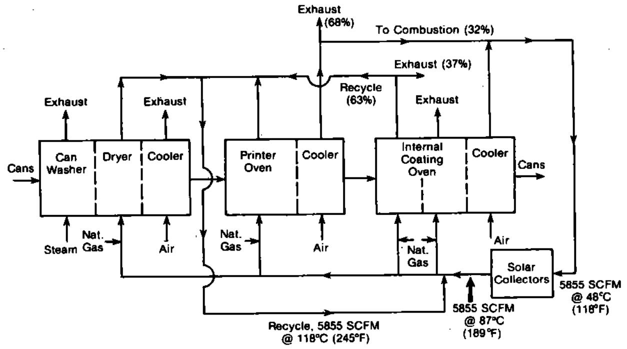


FIG. 4. FLOW DIAGRAM OF RECYCLING HOT GASES AND SOLAR PREHEAT

The can coolers supply 5% of the total process energy requirement (for an average of 10 of the 24 operating hours per day), solar energy provides 12%, and the recycled gases supply 27%. The remaining 56% is supplied by burning natural gas. The energy recovery from the can coolers and some of that from the recycle of hot gas can be achieved without the solar system. However, more oxygen-depleted gas can be recycled with the solar system because the solar-heated portion of the air stream has not been oxygen-depleted by combustion.

The advantage of this configuration is that although the solar system supplies 0.48 GJ (0.45 MBtu)/h, the natural gas displaced is equivalent to 1.8 GJ/h (1.7 MBtu/h).

CONCLUSIONS

Based upon the solar IPH case studies, the following conclusions have been reached:

- For solar energy applications to be competitive over the next 10 years, one or more of four conditions should be met: 1) fuel costs for the existing IPH system are much higher than typical, or 2) the system uses fuel very inefficiently, or 3) solar collector/system costs are substantially reduced from present levels, or 4) the solar system displaces much more fuel energy than it supplies to the process. [This last condition can sometimes be achieved in direct gas-fired heating processes. Hot, oxygen-depleted exhaust gases can be recycled when solar energy is used (depending on process requirements) because less gas needs to be burned and, thus, less makeup oxygen must be supplied. Solar energy is best used in such cases to preheat the incoming makeup air before it mixes with the recycle air.]
- Near-term solar IPH potential is greatest for low-temperature applications in which solar system efficiencies are higher.
- Because of the great potential for industrial use of solar-heated air, additional R&D is needed for air collectors and air system components.

REFERENCES

1. Solar Energy Research Institute. Putting the Sun to Work in Industry. Golden, CO: SERI; September 1979; SERI/SP-34-175.

2. Solar Energy Research Institute. End Use Matching for Solar Industrial Process Heat. Golden, CO: SERI; October 1979; SERI/TR-34-091.

3. Solar Energy Research Institute. Case Studies of Applying Solar Energy for Industrial Process Heat. Golden, CO: SERI; SERI/TR-34-323. To be published.

4. Guthrie, K. M. "Capital Cost Estimating." Chemical Engineering 76 (No. 6, March 24, 1969): pp. 114-142.

5. Perry, J. H.; Chilton, C. H. Chemical Engineer's Handbook. 5th ed. New York: McGraw-Hill Book Co.; 1973.

6. Peters, M. S.; Timmerhaus, K. D. Plant Design and Economics for Chemical Engineers. 2nd ed. New York: McGraw-Hill Book Co.; 1968.

SOLAR INDUSTRIAL PROCESS HEAT CONFERENCE

OAKLAND, CALIFORNIA

October 31-November 2, 1979

GAS RESEARCH INSTITUTE'S
"SOLAR-AUGMENTED APPLICATIONS IN INDUSTRY PROGRAM"

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GAS RESEARCH INSTITUTE'S
"SOLAR-AUGMENTED APPLICATIONS IN INDUSTRY PROGRAM"

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ABSTRACT

The Gas Research Institute (Chicago) contracted with Insights West (Los Angeles) in October 1978 to conduct investigative research to identify the technical factors, management attitudes, and possible outside influences in introducing solar energy to industrial plants. Solar systems to be considered were those augmenting natural gas-fired units with process temperature needs under 550°F. The methodology consists of 200 in-plant interviews of which over 100 were completed by September 1, 1979. Upon completion of the field interviews, process needs determined will be matched with available solar hardware and a list developed and ranked as to the "Most Likely" candidates for solar industrial process heat installations. A follow-on program to expedite industry's acceptance of these prime solar applications is being considered.

In late October 1978, Gas Research Institute (Chicago) contracted with Insights West (Los Angeles) to identify the technical and organizational factors relative to augmenting the use of natural gas with solar energy in industrial process applications. The objectives of this research are:

1. An identification and ranking by Standard Industrial Classification (SIC) of the 10 "Most Likely" industries in which to apply solar energy to industrial processes. Solar applications were limited to those with temperature requirements under 550°F.

2. A determination by 200 field interviews nationally of the process technical requirements best matching current solar hardware capabilities.

3. The development of a matching matrix of available solar hardware to the industrial process heat requirements found during the interviews.

4. Recommendations as to specific end-use applications justifying equipment development projects and/or technical assessment by the natural gas industry.

The First and Second Quarter work consisted of screening and targeting the SIC's for interview and in reviewing prior work in solar industrial process heat. Priorities were developed for field interviews, a standardized Field Interview format (Figure I) was decided upon, and a "Solar State-of-the-Art Presentation" was prepared as a door-opener. Experienced and technically qualified interviewers were used to approach the top management level at the industrial plants to be interviewed.

"SOLAR-AUGMENTED APPLICATIONS IN INDUSTRY"

GURE I

INTERVIEW OUTLINE

MPANY INTERVIEWED: ______________________________

ALE:	1	2	3	4	5
	Nil	Minimal	Adequate	In-Depth	Exceptional
	Adverse	Negative	Neutral	Supportive	Highly Favorable

General

1.	Knowledge of Solar Energy Application	1	2	3	4	5
2.	Solar Installation Experience	1	2	3	4	5
3.	Fuel Substitution Ease (1 = very difficult)	1	2	3	4	5
4.	In-Company Attitude Toward Solar	1	2	3	4	5
5.	Attitude Toward Gas Utility Involvement	1	2	3	4	5

6. Key Decision Maker on Solar Investment? ______________________________

7. Interviewee's Role in Solar Decision 20% 40% 60% 80% 100%

8. Of the Energy Conservation Possible, what Percent Already Accomplished? 20% 40% 60% 80% 100%

9. Energy Cost as Percent of Operating Budget: 5% 10% 15% 20% 25%+

10. Investment Return Required On Equity? ______% On Overall Investment? ______%

11. Payback Period Required for Energy Investments? __________ Years.

12. Any Long-Term Energy Contracts? ____________________ How Long? _______ Years.

13.

	Natural Gas	Electricity	#6 Oil	#2 Oil
Current Utility Costs (Unit)	__________	__________	______	______
1978 Annual	__________	__________	______	______

14. Major Concern for Long-Term (20 Yr.) Fuel Supplies? Nat. Gas? ______ Oil? ______

Technical Considerations

1. Available Roof Area: ____________ Sq. Ft. Shading Problems? ______________

2. Roof Support Problem? ______________________________

3. Available Land Area (Acres) ____________ Urban ___ Rural ___ Value _____ $/Acre

4. Normal Plant Operations Schedule: No. of Shifts _________ Days/Week __________

5. Process Applications in Plant (List Types, such as, Drying, Heat-Treat Furnace, Etc.)
   - a. Under 150°F? ______________________________
   - b. 150-212°F? ______________________________
   - c. 212-550°F? ______________________________
   - d. Over 550°F? ______________________________
   - e. Boiler Feedwater? Yes ____ No ____ Return Temperature: ______________ °F
   - f. A/C Tonnage? ________ Tons. Central Plant? ______ or # Units ____________

6. Age of Plant___________ Is Plant Typical of Industry? __________(If not, explain).

7. What trends are evident in your industry relative to Energy use?

____

8. Is there a Corporate Energy Planning Staff or Person? ______________________
   Contact Name? ______________________________

9. How can we best reach your industry with Solar Information?
   Association(s) ______________________________
   Trade Journal(s) ______________________________

10. Do you see any overriding objection to the application of Solar Energy in your industrial processes other than cost effectiveness? Describe:

____

te of Interview Interviewer

This research is intended to develop a broad, factual input base to confirm or deny the so-far theoretical assumptions being made concerning solar's application in industry. The research is intended to be investigative rather than statistical in its conclusions. Certainly one or two interviews in each 4-digit SIC does not allow extrapolation. One or two interviews in 150 different 4-digit SIC's do provide, however, a meaningful basis of industrial use data upon which to make intelligent judgments.

As of September 1, 1979, fourteen states and over 80 different SIC's have been included in the first 100 interviews. Findings of significance to date are:

1. Nearly every plant (98 of 100) has at least one process use of hot water, hot air, or steam under 550°F.

2. The process heat required in BTU's/Hour in most cases is far beyond the capacity of any reasonably-sized solar energy system. Solar energy can only augment the use of natural gas in industry, not replace it! "Reasonably-sized" was considered to be 50% of the roof area for effective collector square footage.

3. Many manufacturing plants with excellent solar energy applications (e.g. wash tanks, dip tanks, drying ovens et al) work only a daylight one-shift operation. Those working three shifts are normally so high in thermal consumption that solar offers little impact on their total energy needs. In both cases however, solar systems can apply without storage in many applications, thus reducing capital investment costs.

4. Where electric induction heat has been installed, thermal solar energy's use is usually unattractive due to the high economic cost of adapting a thermal loop to the existing equipment. Photovoltaics may someday open this potential up to solar energy or rising electric costs may make conversion attractive.

5. The attitude towards solar-augmented systems is one of outstanding support and hope for the future but dismay for the costs of the present. Many plant managers ran discouraging cost analyses on solar flat-plate systems 2-3 years ago and will need incentives to take a new look.

6. The fuel costs reported so far in the interviews have varied from a low for electricity of 1.59¢/KWH (Louisiana) to a high of 5+¢/KWH in the mid-Atlantic region. Natural gas costs of $1.87/million BTU to over $3.50/million BTU have been indicated. These costs are average annual costs and do not provide the incremental rate block picture. Specific examples should be examined using local utility rates as a reference, not these averages.

7. Although some minor concern for roof mountings has been encountered, no "overriding" obstacles other than cost effectiveness have been encountered in the interviews. One area needing development, however, is the interface between solar heat output and the existing gas energy systems.

8. Of significant applications interest are the large number of plants with

boiler feedwater recovery and return feedwater temperatures in the 140°F-180°F range.

9. Early solar hardware analysis indicates a significant advantage for the evacuated tube collector types of industrial applications having return water temperatures of 120°F-180°F. The second half of this research program will further analyze this indication.

The net result of the Program to date is excellent "real-world" feedback from the industrial segment as to the "Most Likely" fit for solar-assisted gas energy systems. Some excellent applications for cooperative programs are anticipated in pursuing the actual installation of industrial solar systems.

This continuing GRI Program has as its remaining objectives the completion of the second hundred interviews in industry, a review of available solar hardware, a matching of solar hardware to industrial needs in a matrix representation, and an overview of the outside influences that could affect the rate of acceptance of solar by industrial plant management.

The Final Report in December 1979 will itemize the temperature needs, significant process variables, and management attitudes by SIC code of those interviewed. Figure II provides a sample of the SIC types interviewed and a partial look at the process information being gathered. Over 150 different 4-digit SIC's will be interviewed in 30 or more states.

ACKNOWLEDGEMENTS

Special thanks go to Ken Brown and Pete Ketels of SERI for their data base help during this GRI Program and to the numerous Plant Managers, Executives and Engineers who have graciously given their time to the Field Interviews.

SAMPLE PAGE ONLY

FIGURE II

FIELD INTERVIEW SUMMARY

SAMPLE PAGE ONLY

"SOLAR-AUGMENTED APPLICATIONS IN INDUSTRY"

(GRI Contract #5011-343-0105)

CONTRACTOR: INSIGHTS WEST, INC. (LOS ANGELES, CALIFORNIA)

SIC	DESCRIPTION OF INDUSTRY	STATE	PROCESS APPLICATIONS*				
			Under 150°F	150-212°F	212-550°F	Over 550°F	Boiler Feedwater (°F) Return Temp.
2011	Meat Processor -- Pork	Louisiana	X	X	X	0	130°F
2011	Meat Processor -- Horse meat -- (Export mainly)	Texas	X	X	X	0	0
2011	Meat Processor -- Beef	Texas	X	X	0	0	160°F
2016	Poultry Processor	Texas	X	X	0	0	0
2024	Ice Cream Mfg.	Louisiana	0	X	X	0	160°F
2026	Milk Processing	Texas	X	0	X	0	120°F
2030	Jams & Jellies Mfg.	Calif.	X	X	0	0	130°F
2041	Bulgar (Rice Substitute) Mfg. from Wheat Grain	Texas	X	X	X	0	140°F
2044	Rice Milling	Texas	X	X	X	0	0
2047	Pet Food	Penna.	0	X	X	0	0
2048	Formula Feeds -- Pelletized Grains	Texas	X	0	X	0	140°F
2048	Formula Feeds -- Animal Pets and Pelletized Grains	Oklahoma	X	X	X	0	190°F
2051	Baked Goods -- Bread	Texas	X	0	X	0	0
2051	Baked Goods -- Bread & Rolls	Penna.	X	X	X	0	120°F

LONG-TERM AVERAGE PERFORMANCE BENEFITS OF PARABOLIC TROUGH IMPROVEMENTS

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ABSTRACT

Improved parabolic trough concentrating collectors will result from better design, improved fabrication techniques, and the development and utilization of improved materials. This analysis quantifies the relative merit of various technological advancements in improving the long-term average performance of parabolic trough concentrating collectors and presents them graphically as a function of operating temperature for north-south, east-west, and polar mounted parabolic troughs. Substantial annual energy gains (exceeding 50% at 350° C) are shown to be attainable with improved parabolic troughs.

INTRODUCTION

Parabolic troughs are capable of supplying thermal energy over a wide range of temperatures (up to about 350° C) and presently are the leading solar technology in the intermediate temperature range. Several manufacturers have models for immediate application, but the improvement of materials and mechanical components would enhance energy delivery. There is need to reassess the technical merit of improvements that are now possible or would require only moderate development. Those considered in the study pertain to receiver selective coating, reflector properties, and receiver glazing modifications.

ANALYSIS

Methodology

Important to this study was the efficient method of calculation developed by Rabl and Collares-Pereira [1] to predict annual collector energy delivery at a specified location. Collectors are often compared on the basis of peak efficiency curves; a more meaningful basis is the annual energy delivery, because it accounts for off-peak performance and weather variations. This utilizability method involves the calculation of the energy delivery of a parabolic trough for the central day of each month. However, parabolic trough thermal and optical characteristics have been considered in detail so that optical and thermal improvements are validly compared.

A key element of the annual energy calculation is the optimum geometric concentration ratio because it relates thermal and optical performance; i.e., it is the concentration ratio that best balances optical losses with thermal losses. Thus, parabolic trough performance is evaluated for the geometric concentration ratio that maximizes annual energy delivery at each operating temperature.

Eight potentially attractive improvements are evaluated. A reference parabolic trough is defined based on available materials and current technology; it is typical of commercially available parabolic trough concentrating collectors. Each of the eight improvements then define an improved parabolic trough. The annual energy delivery of each improved trough is normalized with respect to the annual energy delivery of the reference trough at the same operating temperature. This ratio of energy delivery is defined as the normalized performance index (NPI). The graphical presentation of NPI versus operating temperature provides an easy determination of the effectiveness of each improvement relative to present technology.

Reference Parabolic Trough and Potential Improvements

The reference trough receiver utilizes a cylindrical glass tube surrounding an absorber tube with a black chrome selective coating. The 90° rim angle reference trough concentrator utilizes a second-surface aluminized-film reflector. Reference trough parameters are:

receiver glazing transmittance	(0.9);
receiver glazing emittance	(0.9);
receiver glazing thickness	[2 mm (0.08 in)];
black chrome absorptance	(0.95);
black chrome emittance	[0.15(100°C), 0.25(300°C)]*;
concentrator hemispherical reflectance	(0.81)**;
reflector nonspecularity (1σ)	(1.6 mrad);
concentrator slope error (1σ)	(6.0 mrad);
tracking error (1σ)	(2.2 mrad); and
receiver/concentrator displacement error (1σ)	(2.0 mrad).

Eight improved parabolic troughs are defined based on the following potential improvements:

(1) selective coating absorptance increase to 0.98;
(2) selective coating emittance decreased to 0.05 (100°C), 0.15 (300°C)*;
(3) back-silvered glass reflector (reflectance increased to 0.95, reflector nonspecularity decreased to 0.5 mrad);
(4) concentrator slope error reduced to 3 mrad;
(5) evacuated annulus receiver;
(6) xenon back-filled annulus receiver;
(7) heat mirror coated receiver glazing (emittance = 0.15, transmittance = 0.94); and
(8) receiver glazing transmittance increased to 0.96.

These improvements are all near-term possibilites. Efforts are underway to increase reflectance through the development of stable, low-cost, back-silvered, thin glass mirrors. On the other hand, fewer efforts are being directed at defining and diminishing concentrator slope errors. Such reductions could result from the use of precision molds, the development of new fabrication techniques, or the development of higher stability substrates. Ways to increase the transmittance of glass have been developed for flat-plate collectors, and these same antireflection coating and etching processes could be adapted to cylindrical

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*Black chrome emittance assumed linear between and beyond these limits.

**Reference trough long-term average reflectance taken from an average of water- and solar radiation-exposed second-surface film samples [2].

line-focus receiver glazings. Selective surface coating development is being actively pursued. Black chrome bath compositions, plating times, and currents are being investigated to improve thermal stability and optical characteristics. Various other coatings are also being developed—some with the potential for very low emittance and therefore reduced receiver heat losses. Other means of decreasing heat losses are receiver glazings coated with heat mirrors and evacuated and back-filled receivers. Back-filled receivers involve filling the annulus between the absorber and surrounding glass with low-conductivity xenon to reduce conduction and convection losses. Development of a parabolic trough receiver that can maintain a vacuum (10^{-3} torr) effectively eliminates conduction and convection within the annulus. A heat mirror coating on the inside surface of the receiver glazing reduces radiation losses from the absorber because of the reduced effective emittance of the glass. However, the solar transmission through the receiver is decreased by the transmittance of the film.

This analysis defines improved performance on the basis of a long-term average, and it must include the effects of accumulated dirt and dust. A long-term average dirt and dust degradation of 6% is included as a modifier to both the concentrator reflectance and glazing transmittance for the reference and improved troughs.

Thermal and Optical Analysis

A thermal model is used to predict heat losses from line-focus parabolic trough receivers. Heat loss is determined as a function of average absorber tube temperature. This eliminates the need to specify the fluid inlet or outlet temperature, rate of flow, and fluid properties.

The thermal model is used to determine receiver heat-loss rates for the reference trough receiver, the evacuated receiver, the xenon back-filled receiver, the heat mirror coated glazing receiver, and the reduced-emittance selective coating receiver. For this study, the absorber tube diameter is held constant at 2.54 cm (1 in). The absorber tube diameter is fixed, but the receiver glazing diameter is sized to minimize the conduction/convection losses. Too small a glass diameter results in excessive conduction losses, whereas too large a glass diameter results in excessive convection losses. For an evacuated receiver, glass diameter sizing is not important because no conduction or convection occurs in the annulus.

Once the effective total optical error is defined, a receiver's heat-loss rate can be used to find the optimum geometric concentration ratio, i.e., the ratio of collector aperture area to absorber tube surface area. The effective total optical error can be calculated by characterizing the sun's size, concentrator slope errors, tracking errors, reflector nonspecularity, and receiver/concentrator displacement errors by Gaussian distributions [3].

After solving for the optimum geometric concentration ratio, the optical analysis is completed with the incidence-angle modifier. The incidence-angle modifier accounts for the variation of optical efficiency with the angle of incidence of incoming radiation. Optical losses are due to the reductions in intercept factor (that fraction of rays incident upon the aperture that reach the receiver) and receiver glazing transmittance and receiver absorptance as incidence angles increase. Our analytical determination of the incidence-angle modifier is in good agreement with published experimental data [4].

RESULTS

Normalized Performance Index

Figures 1a-1c illustrate the performance benefits of parabolic trough improvements in terms of normalized performance indices (NPI) defined for each improvement. The NPI values show how the merits of an improvement vary with operating temperature. The three figures correspond to the three principal tracking orientations: east-west, north-south, and polar.

These results were generated for Denver but can be generally applied to all locations with little error. Sensitivity results indicate increased NPIs for cloudier climates and decreased NPIs for sunnier climates. The variation in NPI from cloudy to very sunny climates has been found to be less than 9%.

Discussion

Substantial performance gains are possible for parabolic troughs due to the increased operating efficiency of the collector and the resulting increase in operating time (an increase in operating efficiency extends operating hours because the threshold value of insolation is lowered).

The performance gains, as represented by the NPI, increase with operating temperature for each of the improvements. This is because of the reduction in the absolute magnitude of trough energy delivery as operating temperature increases. For example, a ten-point increase in collector efficiency represents a larger percentage increase in a collector operating at high temperature (where the annual efficiency may be 30%) than in a collector operating at low temperature (where the annual efficiency may be 60%).

Whereas all the NPI increase with temperature, the rate of increase varies. Improvements associated with increased optical efficiency increase NPI less rapidly than improvements associated with thermal losses; the importance of improvements that reduce thermal losses increase with operating temperature.

At low temperature, thermal losses are small and therefore further reductions are relatively less significant. Optical efficiency improvements dominate in that range; a back-silvered glass reflector has the largest low-temperature performance increase of the improvements studied. An increased receiver glazing transmittance is the second most significant improvement at low operating temperatures. Increasing the selective surface absorptance has only a small impact, because black chrome absorptance has been well developed and little further gain is possible. Mirror reflectance, receiver glazing transmittance, and selective coating absorptance all impact the optical efficiency and for low-temperature operation are the most significant areas in which to introduce improvements.

At higher operating temperatures, thermal losses increase and become more significant to trough performance; they tend to outweigh optical efficiency improvements. Above 150°C, an evacuated receiver shows the largest gain of the improvements that this study considers. A xenon back-filled receiver also significantly increases trough energy delivery with increased operating temperatures. A reduction in concentrator slope error has much the same effect

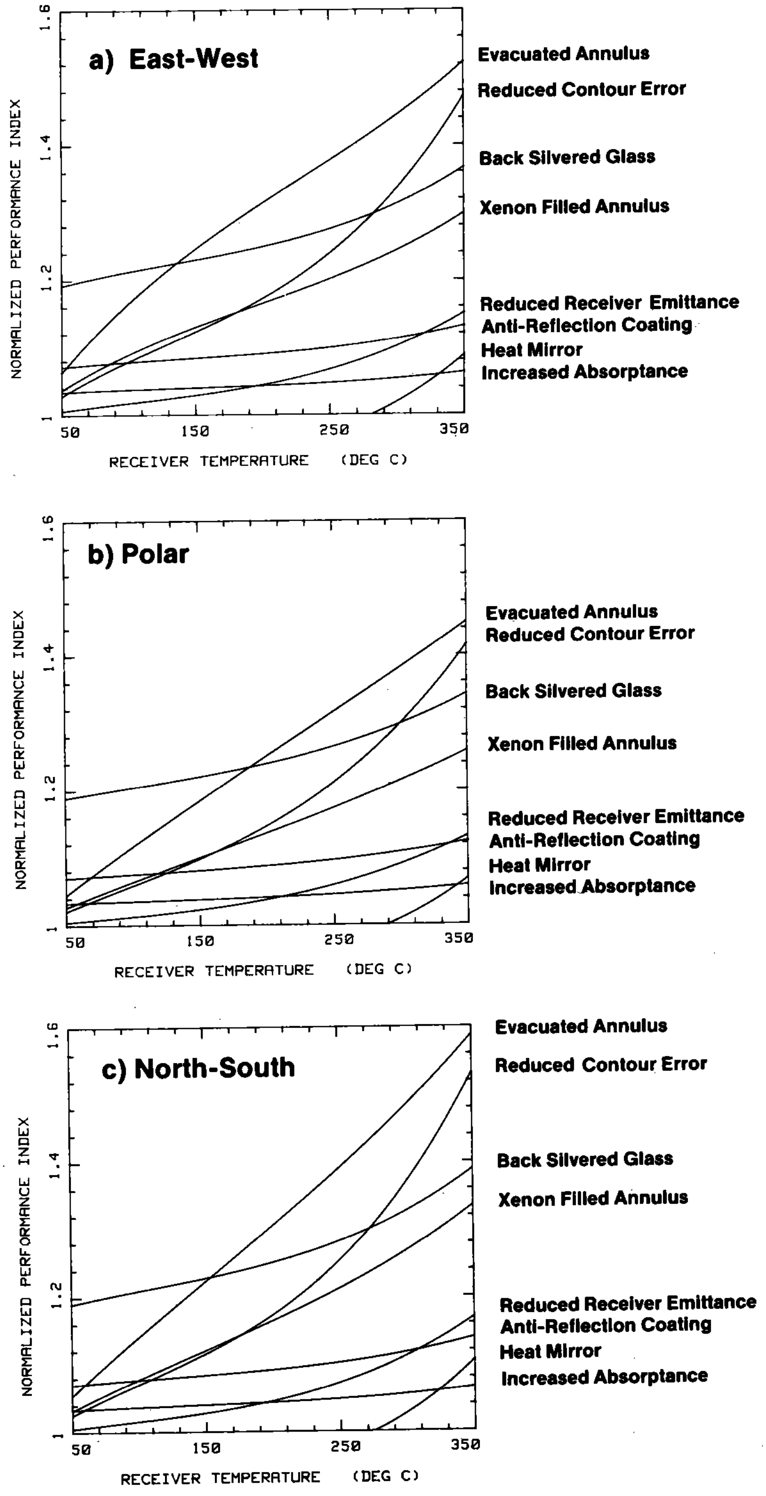

FIGURE 1. PERFORMANCE GAINS FOR IMPROVED PARABOLIC TROUGHS FOR THREE ORIENTATIONS

as thermal improvement because a slope error reduction results in more precise concentrator optics and permits a high concentration ratio trough. Thus, for a given absorber tube size, the optimum aperture area of a parabolic trough increases as slope errors are decreased. This reduces the size of the receiver relative to the concentrator and in effect diminishes thermal losses. Hence, reduced slope error is shown to be a dominant factor in trough performance at high operating temperatures. The merit of heat mirror coated receiver glazings depends strongly on temperature level. Below 275° C, the reduction in thermal losses due to the heat mirror is overshadowed by its reduction in optical efficiency.* Above 275° C, it offers moderate benefit. Decreased selective surface emittance also offers a meaningful performance gain only for high-temperature operation.

The improvements have been considered individually. The performance increase that results from two or more improvements is not the sum of the individual performance increases; one improvement may largely negate potential gains due to another. The performance benefits of combined improvements are considered in the full SERI report [5].

The addition of cost data to the performance data generated in this study will allow the assessment of the improvements on an economic basis. While some of the improvements necessarily involve increased costs, others are potentially low-cost and would add little to total system cost. Further work in this area will address the economic benefits of improved parabolic troughs.

ACKNOWLEDGEMENTS

The authors thank the many individuals from Sandia Laboratories Solar Energy Projects Department and SERI's Materials Branch who supported this project. Special thanks go to Dr. Gideon Yekutieli of the Weizmann Institute of Science, Israel, for his assistance and recommendations.

REFERENCES

1. Collares-Pereira, M.; Rabl, A. Simple Procedure for Predicting Long-Term Average Performance of Nonconcentrating and Concentrating Solar Collectors. ANL-78-67. Argonne, IL: Argonne National Laboratory; 1978.
2. Rausch, R.; Gupta, B. Exposure Test Results for Reflective Materials. Proceeding from Institute of Environmental Science Testing Seminar; Gaithersburg, MD; May 1978; pp. 184-187.
3. Rabl, A.; Bendt, P.; Reed, K.; Gaul, H. Optical Analysis and Optimization of Line Focus Solar Collector. SERI/TR-34-092. Golden, CO: Solar Energy Research Institute; September 1979.
4. Gaul, H.; Rabl, A. Incidence Angle Modifier and Average Optical Efficiency of Parabolic Trough Collectors. SERI/TR-34-246R. Golden, CO: Solar Energy Research Institute; May 1979.
5. Gee, R.; Gaul, H.; Kearney D.; Rabl, A. Long-Term Average Performance Benefits of Parabolic Trough Improvements. SERI/TR-333-439. Golden, CO: Solar Energy Research Institute (to be published).

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*Although using heat mirror coated receiver glazings in conjunction with black chrome is not effective, they may be utilized effectively in place of black chrome or other selective surfaces.

EFFECT OF CLEANING COST ON PROCESS HEAT FROM LINE-FOCUS SOLAR COLLECTORS*

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ABSTRACT

The effect of operation and maintenance (O&M) costs on energy produced by solar collector systems is crucial to the market penetration of solar process heat as an alternative energy source. In the present paper, a particular O&M operation, namely, regular collector cleaning, is considered in order to determine its effect upon annualized life cycle energy cost. A first order model of mirror surface degradation as a function of time is constructed from actual experimental data taken at Albuquerque, NM. This is used as input to a systems optimization model of a line-focus solar collector process heat installation. The energy cost variation is considered as a function of cleaning cost per unit of collector aperture and cleaning interval. Results are presented for a process heat temperature of 177°C (350°F) and two different time-constant values, with a reflector degradation limit of 13%. This information could help in formulating O&M costs to assume in modeling other generic-type solar collectors.

INTRODUCTION

It is customary to divide the cost of power furnished by a generating plant into three parts: the fixed or capital costs, the recurrent costs exclusive of fuel, and finally, the cost of fuel necessary to operate the plant. The recurrent costs include primarily O&M expenses, but also include such items as insurance and property taxes. One facet of the O&M costs of a solar/thermal power plant which has received only token attention is the cost of cleaning reflector surfaces to restore them to their original high reflectance. This cost includes not only the actual expenses incurred for labor and cleaning materials, but also the overall system degradation due to reflector weathering between cleanings. Because in general a system is required to provide a certain power level, it is necessary to provide for system performance loss by fielding additional collectors. This, of course, is reflected in the system capital costs, and indicates a cross-coupling effect which can only be considered by looking at a specific example of a solar collector system.

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† Member of the Technical Staff and Division Supervisor, respectively.

In order to assess reduction in system performance between reflector cleaning, a time-dependent model of surface reflector degradation must be developed. Actual experimental data [1] acquired at Sandia Laboratories, Albuquerque, NM, on silvered glass mirrors is used to construct a first order degradation model. This model is characterized by a time constant and initial and final reflectance levels. A systems optimization model is used to determine the lowest value of annual levelized energy cost (AEC) over the range of parameters relevant to this particular solar/thermal system. For the present work, the collector field is assumed to be a North-South array of advanced parabolic troughs which furnishes energy to a constant demand process heat load.

ANALYSIS

A discussion of the system optimization code used in the study is presented in [2] for a solar/thermal electrical plant. The process heat load of the present study was simulated by defining the efficiency of the heat engine in [2] to be 100 percent. A composite of the actual mirror surface degradation data presented in Reference 1 furnished the first order approximation which is used in the simulation code. Natural cleaning from rain and wind accounts for random fluctuations in the equilibrium portion of the experimental data, but the mean value had clearly changed from the initial high reflectance value. The time constant of the curve used in the study is 44 days. Initial reflectance is 0.92, with the degradation limit of 13% resulting in a final reflectance of 0.80. To simulate faster degradation, a time constant of 11 days was also considered for its effect on system performance. These two time constant values were proposed by the personnel working on the research reported in [1], and should be considered only approximations to the real situation.

The collector, which is an advanced version of a line focus parabolic trough, can be characterized by a linear relationship between collector efficiency and temperature difference divided by the insolation:

$$\eta = \eta_o - \frac{B\Delta T}{I}$$

where

η_o is the optical efficiency of the collector,

ΔT is the average collector temperature minus the ambient temperature,

B is an experimentally determined constant with the proper units, and

I is the insolation level.

For the present work, η_o was assumed to be 0.79, and B was taken as 0.5 W/m^2-K. This linear behavior of a parabolic trough collector has been observed experimentally for both prototype and first generation production collectors [3]. Storage for the system was provided by a dual media system consisting of Caloria HT-43 and rocks. The price of the HT-43 was assumed to be \$1.00/gallon and the collector installed cost was \$140.00/m^2. This price collector is representative of a mature technology and moderately high production rate as anticipated for about 1990. All prices used in the study are expressed in 1978 dollars with an assumed general inflation rate of 8 percent. Actual weather and insolation data were used for the Albuquerque, NM location [4] and the load was taken as a constant demand 1.0 MW$_t$. No penalty was assessed for failing to meet the load requirements, so this corresponds to an optimistic match of supply and demand. The case used to normalize the results was an identical system with a surface reflectance which remained at its original high value.

RESULTS

A comprehensive study of parabolic trough cleaning costs [5] concludes that a reasonable figure to use for a single collector cleaning is \$0.05/m^2 for the total of cleaning materials and labor. The study further concludes that it is unlikely that this number would either increase or decrease by an order of magnitude. Accordingly, the range of collector cleaning costs is varied from zero to \$0.50/m^2. The zero cost case corresponds to a continuously cleaned surface at no net cost. Obviously, this case could never be achieved in a real installation, but it is a useful baseline for normalizing the other results. Using the economics methodology outlined in [6], with a reasonable set of economic parameters, the relative AEC results presented in Figure 1 are obtained. The symbols at the various values of cleaning cost (0.05, 0.10,...) represent a cleaning interval which provides minimum

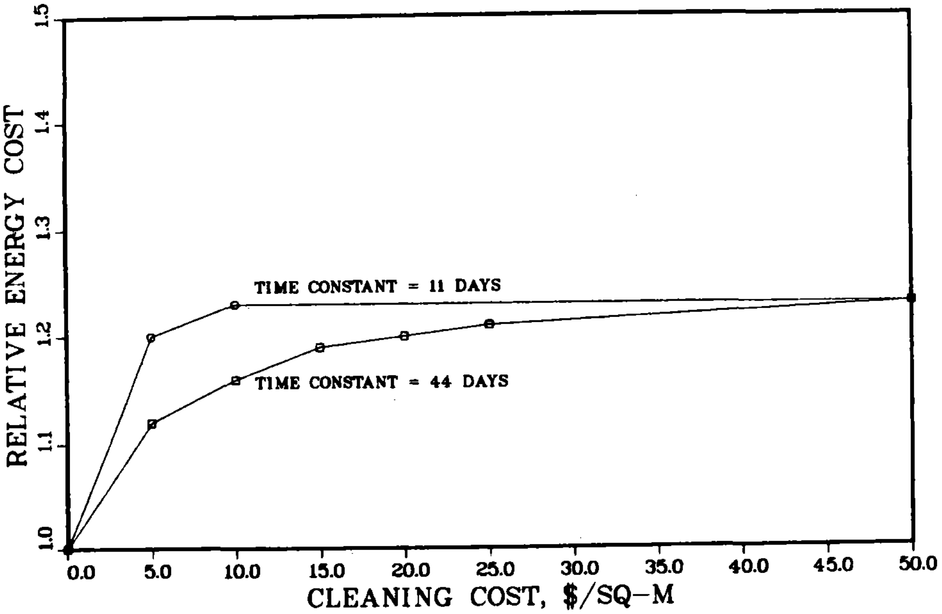

Figure 1. Relative Cost of Cleaning

energy cost. In other words, if the interval is too short, the cleaning costs dominate, while if the interval is too long, the additional collector cost is the dominant consideration. Fortunately, these minima are reasonably flat so that they can be determined by the optimization code. For example, at $0.05/m^2, minimum AEC can be achieved with a cleaning interval of from 22 to 48 days. The limited scope of this paper precludes more than a token mention of this cleaning interval, but it can easily be determined with the systems optimization code. The lines connecting these discrete data are merely for convenience in locating the two time constants. The 44 day time constant line corresponds to the most optimistic case or longest time constant with a moderate degradation limit. Note that even at $0.05/m^2, the relative AEC is some 12% higher than it would be if the surface reflectance remained at its original value. Cleaning more frequently will only drive the AEC higher at this cleaning cost. At a cost of $0.25/m^2 per cleaning, the relative AEC is about 20% higher than the baseline case. The optimum cleaning interval for this latter case is from 40 to 85 days. If the time constant of the degradation curve is taken as 11 days, with the same 13% degradation limit, the results are as indicated by the second curve in Figure 1. Now, even the modest $0.05/m^2 cleaning cost results in a relative AEC increase of some 20%. Furthermore, increasing the cleaning cost results in only a small increase of the relative AEC. This indicates that the computer code has specified a larger collector field with only minimum cleaning, because the alternative would be to clean almost continuously. Hopefully, this latter time constant would not be observed in an actual installation, but there is no experimental evidence to rule it out at present. The horizontal line corresponds to an asymptotic line, which represents the relative cost of never cleaning the reflector surfaces.

CONCLUSION

The cost of cleaning reflector surfaces is a tradeoff between recurrent costs (O&M) and capital outlays (increased collector field). This study has demonstrated that an idealized reflector degradation curve can increase the relative annualized energy cost charged to a solar/thermal process heat installation by some 10-20% at a modest cleaning cost of $0.05/m^2. Since it is unlikely that this cleaning cost can be significantly reduced, it appears that systems simulation codes should be modified to account for the recurrent/capital cost cross-coupling which exists because of collector weathering. Finally, although the results presented in this study are site specific, it seems plausible that this could be an optimistic case because of the temperate climate and infrequent rain at Albuquerque. Hopefully, future experimental studies at additional lcoations will resolve this question by obtaining reflector degradation data.

REFERENCES

1. Freese, J. M., "Effects of Outdoor Exposure on the Solar Reflectance Properties of Silvered Glass Mirrors," SAND78-1649, Sandia Laboratories, Albuquerque, NM, September, 1978.

2. Lukens, L. L., "The Effect of Operating Temperature on the Cost of Energy from Solar Thermal Electric Power Plants," SAND79-0801, Sandia Laboratories, Albuquerque, NM, July 1979.

3. Dudley, V. E., and Workhoven, R. M., "Summary Report: Concentrating Solar Collector Test Results, Collector Module Test Facility (CMTF), January-December 1978," SAND78-0977, Sandia Laboratories, Albuquerque, NM, March 1979.

4. Hall, I. J., et al., "Generation of a Typical Meteorological Year for 26 SOLMET Stations," SAND78-1601, Sandia Laboratories, Albuquerque, NM, August 1978.

5. Unclassified memo, R. L. Champion, 5722, to J. F. Banas, 5722, Subject: "Cost of Cleaning Solar Collectors or Heliostats," dated May 31, 1978, Sandia Laboratories, Albuquerque, NM.

6. Perino, A. M., "A Methodology for Determining the Economic Feasibility of Residential or Commercial Solar Energy Systems," SAND78-0931, Sandia Laboratories, Albuquerque, NM, January 1979.

TEST EXPERIENCE AT THE DOE/SANDIA MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY

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ABSTRACT

Since 1972, Sandia Laboratories, Albuquerque, NM, has been involved in the study, design, construction, testing, and evaluation of solar energy systems. This report presents some of the insights and experience acquired during this period. While the intent is to include only those conclusions that can be supported by actual hardware experience at the DOE/Sandia Midtemperature Solar Systems Test Facility, space constraints do not permit the inclusion of test data and other evidence.

INTRODUCTION

Sandia Laboratories first became actively interested in solar energy in 1972. With support from the U.S. Department of Energy (DOE), the DOE/Sandia Midtemperature Solar Systems Test Facility (MSSTF) has been established to serve as a national engineering evaluation center for midtemperature-range component and subsystem development [1].

The staff of the MSSTF is interested in transferring these insights on solar technology to systems designers, component manufacturers, researchers, and others who will be instrumental in the development of a viable solar energy industry in the private sector. The supporting test data and other evidence are not included here; the reader is referred to Sandia Laboratories test reports for details. Some of the more useful reports are References 1-4.

The MSSTF consists of (1) a Collector Module Test Facility (CMTF) to obtain thermal and optical performance data for prototype collectors of up to about 45 m^2 in aperture, (2) a Systems Test Facility (STF) for evaluating larger collector fields, and (3) other subsystems and components under development for use in the collection and utilization of solar energy in the midtemperature range. Detailed descriptions of the MSSTF are given in References 5 and 6.

INSIGHTS AND EXPERIENCES

The insights are presented in the following categories:

1. Collectors
2. High-Temperature Thermal Energy Storage
3. System

The third category includes insights which relate to the operation of subsystems in concert and miscellaneous observations that do not fit into the first two categories. Reference 7 provides a detailed report.

1. Collectors

Reference 4 evaluates several collector concepts.

Some general observations relative to collector performance are:

- Peak efficiencies for line and point focusing collector modules have been measured as high as 64 percent and 78 percent (180°C), respectively, with projections to 65 percent and 80 percent (300°C).
- Selective absorber coating provides a measured performance improvement of 24 percent over nonselective at 280°C output and solar noon conditions, and even more when output is integrated over time.
- Vacuum jacket on receiver contributes 5 to 10 percent to peak output, but sealing is expensive and pumping requires much parasitic power.

General insights relative to collector design are:

- Metalized film reflector surfaces are easily damaged, require frequent cleaning, and degrade with exposure.
- Analysis supported by experiments indicates that, in general, linear focusing collectors with a horizontal north-south axis outperform east-west (E-W) collectors by about 10 to 25 percent in terms of integrated annual energy collected. From season to season, however, E-W collectors produce a more balanced output.
- Computerized position tracking is superior to sun-sensing tracking system.
- Two-speed tracking and drive systems are desirable.
- Face-down stow position minimizes problems from dirt, snow, ice, etc.
- Thermal losses are important because they are essentially independent of solar flux.
- Receiver glazing is beneficial at 315°C operating temperature.
- Due to induced temperature gradients in receiver glazing, it is necessary to take precautions against stress concentrations at rough edges.
- Accuracy requirements for foundations are beyond normal construction practice.

Some insights into the development of operational strategies for collectors are:

- Start-up scenarios require careful trade-offs between collectible energy and parasitics.
- Periodic cleaning is required. Performance losses of 5 percent are typical for the first week after cleaning.

2. High-Temperature Thermal Energy Storage

Observations from experience with those systems installed in the MSSTF are:

- Stratified (thermocline) and multitank thermal storage concepts are demonstrated.
- Measurements on field-size installations of thermocline and multitank concepts have shown thermal loss of about 5 percent per day.
- Phase-change storage remains an attractive candidate but needs development.
- Rigorous measures to minimize thermal losses through insulation, supports, and supply lines should be included in the system design.
- Thermal siphoning can cause substantial energy loss when the fluid is not being circulated.

3. System

Testing has given the following insights into system configuration and design:

- Feasibility of solar total energy system configuration is demonstrated. Delivery of 65 percent of the collected solar energy to electrical and thermal loads has been measured.
- Automatic switchover between solar and fuel to maintain constant system output is feasible.
- Therminol-66 functions well as the collector and storage fluid up to 315°C.
- At 315°C, water is less desirable because of requirement for freeze protection and much higher working pressures.
- Standard power plant practice, such as in the selection of equipment and materials, the definition of hazards, etc., is often inadequate for or not applicable to solar power systems, which require "solar-specific" analyses and trade-off studies.

- Penetrations in system insulation for valves, supports, instrumentation, pumps, etc., should be minimized to reduce thermal loss.

- Compression fittings and welding are more reliably leak-tight than threaded joints.

Observations relating to parasitic power and thermal losses are:

- Interconnecting piping, valves, pumps, etc., must be of energy conserving design.

- Proper installation of piping and thermal storage tank insulation is critical and must be superior to standard practice.

Observations pertaining to materials are:

- Operating temperature is presently limited by heat transfer fluid and selective absorber coating.

- Exposure of system insulation to operational temperatures has produced changes in color and brittleness. The impact on conductivity is unknown.

- Thermal cycling in the presence of high-temperature heat-transfer oil has degraded asbestos gaskets, packing in valves, insulation, and O-rings.

- Graphite products have been found effective as gaskets and packing material.

- Ceramic pastes have been superior to epoxy as a filler around instrumentation probes.

Operations and maintenance experiences are:

- Systems should be flushed after any welding.

- Sticking control valves have been a major maintenance item.

- The long transit time required for fluid to pass through the field creates a difficult control problem, particularly if a constant temperature output is required.

- In spite of reasonable care, foreign material has been present in the fluid loops. Cleanable/replaceable filters are recommended.

- Output data from flow meters have been particularly unreliable.

- Damage from a moderately severe hailstorm (winds to 52 kph and hailstones up to 19 mm in diameter) was generally confined to improperly supported glass less than 3.2 mm thick.

- Leaks of heat-transfer oil into fibrous insulation create a significant fire hazard.
- Conventional sunglasses potentially increase the eye damage hazard for persons working near concentrating solar collectors.
- Specifications for solar protective glasses for MSSTF personnel have been developed.

ACKNOWLEDGMENT

The insights and experiences listed in this report are the results of the work of many people, including the staff of the MSSTF, personnel from other project and support groups within Sandia, program management personnel from the Department of Energy/Division of Central Solar Technology, and innumerable contractor personnel. The author gratefully acknowledges the contributions of these people to the material presented here. This work has been supported by the Division of Solar Technology, USDOE, under contract DE-AC04-76DP00789.

REFERENCES

1. FY79 Annual Operating/Management Plan, Midtemperature Solar Systems Test Facility Project, SAND78-0987, Sandia Laboratories, Albuquerque, December 1978.

2. McCulloch, W. H. and Zimmerman, J. C., Small Solar Thermal Power Systems Projects Semiannual Report -- October 1977-March 1978, SAND78-0951, Sandia Laboratories, Albuquerque, February 1979.

3. Harrison, T. D. and McCulloch, W. H., Midtemperature Solar Systems Test Facility (MSSTF) Project Test Results: Phase IVA MSSTF System Operation, SAND78-1088, Sandia Laboratories, Albuquerque, November 1978.

4. Dudley, V. E. (EG&G, Inc.) and Workhoven, R. M., Summary Report: Concentrating Solar Collector Test Results -- Collector Module Test Facility (CMTF) -- January-December 1978, SAND78-0977, Sandia Laboratories, Albuquerque, March 1979.

5. Leonard, J. A., "Operating Experience at the DOE/Sandia Midtemperature Solar Systems Test Facility," Proceedings of the 13th Intersociety Energy Conversion Engineering Conference, San Diego, August 1978.

6. Otts, J. "Results of the Solar Total Energy Program," Sandia Laboratories, Albuquerque, to be published.

7. McCulloch, W. H., "Insights and Experiences from the DOE/Sandia Midtemperature Solar Systems Test Facility," Sandia Laboratories, Albuquerque, to be published.

LOW TEMPERATURE INDUSTRIAL PROCESS HEAT FROM NON-CONVECTING SOLAR PONDS

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ABSTRACT

A unique class of integrated solar collector/storage concepts are described. A variety of non-convecting solar ponds are surveyed and ranges, performance, and costs are discussed.

INTRODUCTION

Several studies have estimated the usage of industrial process heat at temperatures below 100°C (212°F)[1,2,3] is between two and five percent of the nation's total energy needs.

Because of political, social, technical and economic constraints, only a portion of this total industrial process energy demand will likely be met by solar energy. However, a significant market exists for a cost-effective method for collecting and storing solar energy at or below 100°C. The non-convecting solar pond is a strong candidate for this need.

DESCRIPTION OF THE NON-CONVECTING SOLAR POND

In the non-convecting solar pond, solar energy passes through the liquid and is absorbed by the liquid and the darkened pond bottom (Figure 1). A non-convecting layer of liquid (usually water) acts as transparent insulation to retain much of the absorbed energy in the bottom convecting layer.[4,5,6] This thermal energy may be extracted from the bottom convecting layer by various exchange mechanisms. The most important element of the solar pond is the non-convecting layer of liquid which reduces energy loss from the pond.

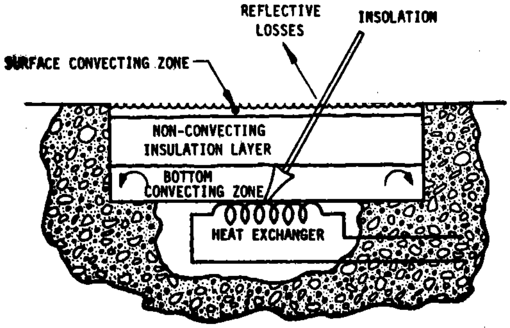

Figure 1. Cross-Section of Solar Pond

Good conductors such as metals exhibit conductivities ranging from 50 BTU/hr-ft-F^o to 200 BTU/hr-ft-F^o, while good thermal insulators exhibit a conductivity of approximately 0.02 BTU/hr-ft-F^o. Water has a conductivity of approximately 0.3 BTU/hr-ft-F^o which is two to three orders of magnitude less than a good conductor and only one order of magnitude greater than the best insulators. Thus, if the only mechanism for heat loss from the pond is restricted to conduction (no convection), then a relatively shallow pond (less than 2 meters) can retain a significant portion of the energy striking its surface over the period of a day. There are a variety of methods which can be used to establish the essential non-convecting layers in a solar pond. The next section briefly discusses the better-known techniques.

METHODS OF SUPPRESSING CONVECTION

Salinity Gradient

Until recently, the only mechanism used to create and maintain a non-convecting density gradient has been to carefully layer the pond with salt solutions. The most concentrated, and thus most dense brine solution is placed at the bottom and successively less-concentrated, and thus less dense brine layers are added, ending with a surface of fresh water at the top.[4,5,6] Diffusion smooths the stepped density gradient and establishes a non-convecting pond with the heaviest water at the bottom. Unfortunately, diffusion from the more concentrated zones of the pond to the dilute zones results in a constant transfer of salt which tends to destroy the density gradient. To prevent this gradient destruction, concentrated brine is pumped into the bottom of the pond while the surface is flushed with fresh water. This is similar to the mechanism which creates and maintaines solar ponds found in nature.[7] Similar methods have been used successfully with virtually all of the solar ponds operating throughout the world. Some of these ponds have been in continuous successful operation producing useful heat for many years. However, this method of maintaining the non-convecting gradient is labor intensive and water intensive. Therefore, other means of suppressing convection are being investigated by researchers throughout the world.

Saturated Pond

The use of a salt with a highly temperature-dependent solubility enables the pond to create and stabilize its own density gradient. In this concept, sunlight heats the water near the pond bottom which is then able to absorb more salt than the cooler layers above it. Excess salt is available at all levels of the pond so that the warm water at each level can absorb as much salt as it can dissolve. In theory, this phenomenon produces a stable density gradient which does not need to be maintained like the non-saturated salinity gradient pond discussed above. The saturated solar pond normally requires significantly more salt than the non-saturated pond. This advantage may be outweighed by lower operating costs and improved thermal performance. Limited theoretical investigation of this phenomena has been completed and an operating demonstration pond utilizing borax has been constructed.[8,9]

Gel Stabilized Pond

If the pond is gelled, convection will be completely suppressed. Gelling agents are available which will produce a non-convecting pond on a small scale basis, but only for relatively short periods of time. These gelling agents tend to breakdown with exposure to solar radiation. The only known gel stabilized pond is currently in operation in France.[10] However, there is little data currently available on this non-convecting pond concept.

Viscosity Stabilized Pond

Rather than completely gelling the pond, viscosity is dramatically increased in order to retard convection.[11] Commercially available thickening agents could prove to be useful in this pond concept. There are no known viscosity stabilized ponds presently in operation.

Membrane Ponds

There are presently two different membrane pond concepts under investigation. The first concept relies on transparent membranes to separate the bottom convecting zone and the top convecting zone from the non-convecting layer in a non-saturated saline gradient pond.[12] The purpose of these membranes is to stop degradation of the non-convecting zone by the upper and lower convecting zones. This concept has not been verified in an operational pond.

A second membrane pond concept utilizes many vertical thin, transparent membranes in pure water. Membrane surface effects in conjunction with water viscosity should effectively suppress convection.[13] This concept has not been investigated experimentally.

TEMPERATURE RANGES

As noted earlier, the amount of industrial process energy required at temperatures below 100°C is significant. Solar ponds have the capability of producing temperatures ranging from just above ambient to as high as 135°C. Solar ponds are essentially horizontal flat plate collectors, and thus, their performance suffers in the winter and at extreme latitudes unless a reflecting cover is used.[14]

Generally the temperature limit of solar ponds is determined by the boiling point of the liquid (usually water). Newer concepts will potentially extend the operating range up to a working temperature of approximately 135°C. This increase in working temperature can be obtained by greatly lowering the vapor pressure in highly concentrated brine solutions or through the use of alternate bottom fluids having higher boiling points.

THE ADVANTAGES OF NON-CONVECTING SOLAR PONDS

Non-convecting solar ponds offer two significant advantages over conventional solar collection and storage concepts. The first advantage is that the ponds combine solar collection, energy storage and to a certain extent energy transport within the body of the pond itself. The large thermal mass associated with the water in the lower convecting zone of the pond can store significant quantities of energy. Since long-term insulated storage is normally expensive in conventional solar systems, solar ponds are especially attractive when energy storage is a requirement. In addition, the soil below the pond can enhance the thermal storage inherent in the water mass.

The cost of constructing solar ponds is considerably less than conventional flat plate or concentrating collector systems. Standard construction procedures for large shallow bodies of water are well documented and studies are presently being conducted to identify liners which will be suitable for large scale, long-term operation. Using low cost or "free" salts which are by-products of many industrial processes, projected non-convecting solar pond costs range from $10 to $30 per square meter.

AREAS REQUIRING ADDITIONAL RESEARCH AND DEVELOPMENT

Each of the variety of non-convecting solar ponds has a distinct set of advantages and disadvantages. Some concepts may never be more than interesting laboratory phenomenon. Only after these and other concepts have been investigated over the next several years will we be able to determine the appropriate role for non-convecting solar ponds.

Some of the areas requiring further research and development are:

1. Methods for reducing labor and water requirement.
2. Improved materials for ponds, liners and covers.
3. A determination of environmental effects.
4. Stability criteria for the various types of ponds.
5. Optimization and simulation concepts.
6. Optimization of heat extraction techniques.
7. Studies of crystalization in saturated ponds.
8. Effects of contamination on pond performance.
9. Effects of water clarity upon pond performance.
10. Ways of controlling biological growth within ponds.
11. Systems studies in comparison of solar ponds to other solar collection and storage concepts.

SUMMARY

Non-convecting solar ponds show great promise of dramatically reducing the cost of collecting and storing solar energy for industrial process heat applications. However, many questions need to be answered before large scale commercialization of non-convecting ponds can occur. Currently the non-saturated saline gradient pond is closest to commercialization and has been used successfully in Israel. Presently, there are few non-convecting experimental ponds in the United States. Through increased R&D, and an expansion of experience with non-convecting ponds, it is likely that they will play a significant role in providing low temperature industrial process heat in the years to come.

References

1. E. Hall, "Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat", ERDA Report TID-27348/1. Columbus: Battelle Columbus Laboratories, 1977.
2. M.D. Fraser, "Analysis of the Economic Potential of Solar Energy to Provide Industrial Process Heat", ERDA/Inter-Technology Report #00028-1, Warrenton: Inter-Technology Corporation (1977).
3. Alan B. Casamajor, Richard L. Wood, "Limiting Factors for the Near-Term Potential of Solar Industrial Process Heat". LLL #UCRL-52587, Lawrence Livermore Laboratory, 1978.
4. Hershel Weinberger, "The Physics of the Solar Pond". Solar Energy, Vol. 8, No. 2, pp. 45-56, 1964.
5. C. E. Nielsen "Non-Convective Salt Gradient Solar Ponds". Solar Energy Handbook, Edited by W. C. Dickinson and P. N. Cheremisinoff, to be published by Marcel Decker, Inc., 1979.
6. F. Zangrando and H. C. Bryant, "A Salt Gradient Solar Pond". Solar Age, Vol. 3, No. 4, April 1978.
7. A. V. Kalecsinsky, Uber die Ungarischen warmen und heisen Kochsalzseen als naturliche Waermeaccumulatoren. Ann. Physik IV, 7, 408, 1902.
8. T. L. Ochs and J. O. Bradley, "The Physics of a Saturated $Na_2O\cdot 2B_2O_3\cdot 10H_2O$ Non-Convecting Solar Pond", Proceedings 1979 ISES Meeting in Atlanta, Georgia, May 1979.
9. T. L. Ochs and J. O. Bradley "Stability Criteria for Saturated Solar Ponds". Proceedings 14th Inter-Society Energy Conversion Engineers Conference, August 5-10, Boston, Mass. 1979.
10. J. Jourdan, Personal Correspondence, Sept. 1979.
11. Lloyd H. Shaffer "Viscosity Stabilized Solar Ponds". SUN, Mankinds Future Source of Energy, Proceedings of the International Solar Energy Society Congress, New Delhi, India, January 1978.
12. Ari Rabl and Carl E. Nielsen, "Solar Ponds for Space Heating". Solar Energy, Vol. 17, pp. 1-12, 1975.
13. John R. Hull "Membrane Stratified Solar Ponds". Proceedings of 1979 ISES Congress, Atlanta, Georgia, May 28, June 1, 1979.
14. C. F. Kooi, "The Circular Cylindrical Reflector: Application to a Shallow Solar Pond Electricity Generating System". Lockheed Missiles and Space Company, Electro-optics Laboratory, Palo Alto, Calif.

THE SOLAR TOTAL ENERGY PROJECT AT THE SANDIA LABORATORIES MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY (MSSTF)

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ABSTRACT

Sandia Laboratories, a prime contractor to the United States Department of Energy (DOE), has established the Midtemperature Solar Systems Test Facility (MSSTF) for the DOE at its Albuquerque, NM, site. The MSSTF serves as a national engineering evaluation center for solar total energy systems--systems which provide electrical power generation along with thermal energy for heating and cooling. The MSSTF consists of (1) the collector module test facility which evaluates troughs and dishes and (2) the solar total energy test facility which is used for system and subsystem development as well as operation and maintenance experience on a total energy system. The solar total energy test facility is described, test results are presented, and the future plans for the facility are outlined. A detailed report is given in SAND79-1154 (to be published).

INTRODUCTION

Representative system tests were conducted at the MSSTF on 5 December 1978 with the turbine/generator operating at 26 kW and on 21 December 1978 with the turbine/generator operating at 32 kW. The weather conditions on 5 and 21 December 1978 were nearly identical. Before the first test, the glazings covering receivers and the reflector mirrors were cleaned on all the collector subsystems. No cleaning was done between tests. On 6 December, after completion of the 5 December tests, a violent blizzard occurred. Dirt deposited by this storm reduced the efficiency of the collectors for the 21 December tests.

PURPOSES OF THE TESTS

The purposes of these tests were to (1) establish baseline operating conditions against which future variations in control strategy can be evaluated, (2) measure the net energy collected and the net electrical and thermal energy produced by the system under the baseline conditions, (3) evaluate electrical parasitic power losses under the baseline conditions, and (4) evaluate the effect of severe weather (this purpose added as a result of the severe storm on 6 December 1978).

DESCRIPTION OF THE SOLAR TOTAL ENERGY SYSTEM

The collector field for the solar total energy system included four different collector designs: three were parabolic trough designs arranged on an east-west axis to track the sun in elevation angle only; the fourth was a parabolic dish using two-axis tracking which was not used during the tests on 5 and 21 December 1978. Also included in the system were a High-Temperature Multitank Thermal Storage Subsystem, a Rankine Cycle Turbine for electric power generation up to 32 kWe, a Heat Load System to use the low-temperature heat rejected by the turbine system, and associated heat transfer, control, and tracking subsystems. A complete description of the system is given in Reference 7.

TEST PROCEDURE

Since the total collector area is too small to supply the estimated 2,600 kWh (9.4×10^6 kJ) thermal energy required to run the turbine during the test, the collectors were supplemented with fossil fuel heaters. On the days preceding each of the tests, all thermal subsystems were brought to the desired initial status. At 0800 on the morning of the test, the collectors were turned on, and the turbine/generator was started, using the fossil fuel heater as an energy source.

DISCUSSION OF TEST RESULTS AND IDENTIFICATION OF PROBLEMS

A detailed discussion of tests performed at the MSSTF is given in SAND79-1154. A summary of test results is given in Table 1.

The performance of collectors has been somewhat disappointing [2,3]. Collector efficiencies fall off with time, probably due to the deterioration of the black chrome selective surface coatings. The high thermal masses in the receiver assemblies require long warmup times (as much as 35 percent of available operating time). Better optical alignment is needed to reduce the amount of energy which misses the absorber.

Performance of the system for the 21 December tests is generally poorer than for the 5 December tests. This drop off in performance is largely attributable to the 6 December storm which deposited sand and dirt on the collector systems. Ice forming on reflectors trapped even more dirt. In one instance, reflectance decreased from 0.94 to 0.82.

Losses from the fluid loop and the thermal storage have continued to be greater than the original predictions of 4 and 6 percents, respectively.

The turbine/generator [4] performs at lower efficiencies than is theoretically achievable in this temperature regime [5]. The primary reason for the low efficiency is that the turbine is a modified version of a 100-kW model. Not all components of the turbine were scaled down to be compatible with the 32-kW output.

Thermal losses from the prime mover were larger than from any other subsystem and are attributable to (1) energy required to heat up the prime mover, (2) energy losses at the liquid boiler, (3) energy required to operate the toluene pump which is driven mechanically from the turbine, (4) energy losses from the condenser and associated piping, and (5) energy remaining in the prime mover after it is shut down.

Fluid at temperatures too low for use in the liquid boiler accumulates at the bottom of the thermal tank and in temporarily unused portions of the fluid loop resulting in problems of producing vapor of the proper quality to operate the turbine/generator. Operational strategies have been developed to overcome this problem. The energy required to heat up the system after overnight shutdown extracts a big penalty from efficiency, especially on short winter days. For example, if heatup energy is ignored, energy production efficiencies are sharply increased.

CONCLUSIONS

The use of solar energy to produce electric power and usable thermal energy simultaneously is technically feasible. The test data indicate that the major reductions in system efficiency result from thermal losses from the high-temperature storage and fluid loop subsystems, thermal and parasitic energy losses from the power subsystem, and thermal energy losses from the system after shutdown which must be resupplied by the auxiliary heater before start-up. The detailed insights and experiences gained in the conduct of this project are reported in SAND79-1155.

FUTURE TEST PLANS

Because the feasibility of the overall concept has been demonstrated, system demonstration will be de-emphasized in favor of subsystem studies and analyses. The MSSTF will be maintained to allow a modular capability in support of DOE, particularly, in support of work associated with the collector development plans. The assessment of economic factors will be pursued. System parasitic and thermal loss studies will be continued.

ACKNOWLEDGMENT

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REFERENCES

1. Sandia Solar Total Energy Test Facility Project Final Report, Suntec 260 Square Meter SLATS Subsystem, Suntec Systems Inc., St. Paul, November 1977.

2. Harrison, T. D., Solar Total Energy System Facility Project Semiannual Report, April-September 1976, SAND76-0662, Sandia Laboratories, Albuquerque, April 1977.

3. Harrison, T. D. and McCulloch, W. H., Midtemperature Solar Systems Test Facility (MSSTF) Project Tests Results: Phase IVA MSSTF Operations, SAND78-1088, Sandia Laboratories, Albuquerque, November 1978.

4. Abbin, J. P., Solar Total Energy Facility Project Test Results, Rankine Cycle Energy Conversion Subsystems, SAND78-0376, Sandia Laboratories, Albuquerque, April 1978.

5. Barber, R. E., "Current Costs of Solar Powered Organic Cycle Engine," Solar Energy, Pergamon Press, Parkville, Victoria, Australia., 20:1 (1978).

6. Rambach, G.,* Evaluation of Solar Rankine Cycle Engine Systems, SAND78-0986, Sandia Laboratories, Albuquerque, January 1979.

7. McCulloch, W. H. and Zimmerman, J. C., Small Solar Thermal Power Systems Projects Semiannual Report, SAND78-0951, Sandia Laboratories, Albuquerque, February 1979.

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TABLE 1

System Test Data, 5 and 21 December 1978

	5 Dec.[a]	21 Dec.[b]
Added Energy (kWh)		
From Thermal Storage	541	549
From Collectors		
FMSC	291	224
SLATS	315	258
E-W Parabolic Troughs	284	296
Subtotal from Collectors	(890)	(778)
From Fossil Fuel Heater	1,221	1,554
Totals	2,652	2,881
Energy Used (kWh)		
Losses Overnight from Thermal Storage (1600-0800)	122	95
Losses Overnight from Fluid Loop (1600-0800)	60	60
Losses during Testing from Thermal Storage (0800-1600)	61	48
Losses during Testing from Fluid Loop (0800-1600)	139	284
Electric Energy Produced by Turbine	168	231
Thermal Energy Derived from Condenser	1,154	1,421
Thermal Losses from the Prime Mover	870	647
Energy in Storage and Fluid Loop at End of Test	78	95
Totals	2,652	2,881
Efficiencies (Percent)		
Collectors, Solar to Thermal[c]		
FMSC	16.0	11.0
SLATS	17.3	12.8
E-W Parabolic Trough	20.3	19.2
Overall Collector System	15.0	14.0
Energy Production[d]		
Thermal to Electric	6.0[e]	8.0
Thermal to Thermal	44.0	49.0
Overall Energy Production	50.0	57.0
Energy Losses as a Percentage of Energy Added (Percent)		
Fluid Loop	7	12
Thermal Storage	7	5
Prime Mover	33	22
Totals	47	39
Parasitic Energy (kWh)		
Collectors		
FMSC	2.3	2.3
SLATS	5.3	6.0
E-W Parabolic Trough	1.0	1.0
Pumps		
Boiler Pump	21.0	21.0
Turbine Condenser Pump	36.0	52.0
Turbine Generator Skid	15.0	21.0
Totals	116.6	155.3

[a] Operating at 26 kW.

[b] Operating at 32 kW.

[c] Collector thermal energy output divided by direct normal solar energy input.

[d] Output energy divided by energy added.

[e] Turbine/generator is less efficient at lower outputs.

PRELIMINARY DEFINITION AND CHARACTERIZATION OF A SOLAR INDUSTRIAL PROCESS HEAT TECHNOLOGY AND MANUFACTURING PLANT FOR THE YEAR 2000*

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ABSTRACT

A solar industrial process heat technology and an associated solar systems manufacturing plant for the year 2000 has been projected, defined, and qualitatively characterized. The technology has been defined for process heat applications requiring temperatures of 300°C or lower, with emphasis on the 150°-300°C range. The selected solar collector technology is a parabolic trough collector of the line-focusing class. Major manufacturing processes to be introduced into the year 2000 plant operations are glass-making, silvering, electroplating and plastic-forming. These operations will generate significant environmental residuals not encountered in present day solar manufacturing plants. In addition, national level evaluations of the economic and environmental impacts of expanded solar technologies will have to account for these new operations for new solar manufacturing plants that may be located at enlarged or new industrial sites across the nation.

INTRODUCTION

The primary objective of the study was to define and characterize qualitatively a prospective solar industrial process heat technology (for temperatures of 300°C and lower) and its associated manufacturing plant for the year 2000. The year 2000 is a key milestone in the DOE solar energy commercialization plan. For both solar utilization planning and environmental analysis, it represents a time distant enough that new economies, new energy technologies, and new environmental perspectives are likely to be in place. Therefore, this study required that solar energy for process heat be examined from the perspective that applications, technologies, and manufacturing processes which exist today will influence the year 2000, but that significant advances are expected to occur over the forthcoming twenty years.

INDUSTRIAL PROCESS HEAT APPLICATIONS

The specification of a solar process heat technology applicable to temperature requirements equal to or less than 300°C is based upon independent studies. Process heat constitutes 68.4% of industrial energy use in the United States. Twenty-seven percent of that process heat is at temperatures below 288°C and low pressure steam represents 80% of the steam requirements in industry. Hence, a prime market exists for a moderate temperature, steam-producing solar process heat technology.

SOLAR COLLECTOR TECHNOLOGIES

Five basic collector types were considered for the characterization of current technology and manufacturing procedures, as follows: flat plate, evacuated tube, line-focusing, point-focusing and heliostat power towers. The parabolic trough line-focusing collector was chosen. It is the front runner in current industrial applications and commercialization efforts. It offers considerable flexibility for matching with process heat requirements and for installation. The parabolic trough collector both needs and will achieve technological improvements. Its requirement for large unit areas of reflective surface shaped to a parabolic configuration offers considerable opportunity for new and sophisticated materials and manufacturing processes. It also offers a comparison of alternative materials for the basic elements (e.g., glass vs. metal vs. plastic).

Reflector Materials: Reflector materials are still being developed and demand a definite need for a low cost, high efficiency material on a commercial scale. The three primary materials are glasses, metals, and plastics. Thin glass offers the greatest potential for providing a hard, thin protective coating to a silvered surface. It can be bent to fit a parabolic shape without the need for sagging under heat. However, since the glass is thin, handling presents a difficult problem. Production techniques are required in which the glass is produced, silvered, and placed on a parabolic trough support structure in a continuous operation.

Parabolic Trough Support: The support structure is a major materials item in the collector assembly. The structure offers opportunities for reduction in cost and for fast mass production operations. The material chosen for this study is the Sheet Molding Compound. It represents a low cost production capability and offers a reduction in assembly components. However, it is also representative of materials which will escalate in price as conventional fuel costs increase. Improvements in technology and manufacturing techniques will be required if this material is to be used.

Absorber: The absorber must be able to contain liquid at high pressure (100-1000 psia) and at high temperature (300°C and higher). Heat losses at the high temperatures must be minimized. The material selected consists of steel pipe which will be nickel plated, and then black chromed. The steel offers low cost properties and the black chrome process is an established method. However, black chrome processes will require improvement and better quality control to remain a competitor.

OVERVIEW DESCRIPTION OF MANUFACTURING PLANT

The plant characterized in this study is a large capacity plant (producing ten million square feet of collector) that manufactures parabolic trough collectors. It could easily add other types of line-focusing and point-focusing collectors to its production activity. A large operation benefits from having most of the collector manufacturing carried out within the plant.

The actual design of the collector would require several different special components and materials, including a glass reflector, Sheet Molding Compound, black chromed absorber tubes, sun-sensors and controls, and the tracking drive mechanism. All these items would require an expanded and continuous manufacturing operation, unlike those being carried out in the solar collector industry today.

An analysis of the manufacturing techniques required indicates that the glass making, silvering, and mounting to a parabolic trough shape should be carried out in one continuous process to avoid excessive handling.

REQUIREMENTS FOR THE SOLAR MANUFACTURING PLANT

The characterized plant contains a representative sampling of the materials, manpower and energy requirements. Raw materials would be required for the glass making, plastic molding, silvering, and electroplating processes. Structural materials such as steel and aluminum would be required, as well as a large variety of components and parts for the fabrication operations. With the large quantities of raw materials required for the glass operation, it is likely that the plant will require railroad spurs and bulk storage facilities for such items as sand, soda ash, cullet, and lime. Other bulk materials, but used in lesser quantities, include chemical ingredients for silvering, electroplating, painting, and plastics-forming, and components and parts which would be used in the assembly operations.

ENVIRONMENTAL RESIDUALS FROM THE MANUFACTURING PLANT

The actual environmental residuals depend on the manufacturing process. Operations such as glass making, electroplating and silvering are not currently being conducted in the solar industry, but are being performed by the respective specialty industries. The proposed scale of operation, with the specific process and material requirements indicated, would probably conduct these processes in-house. Such operations require more energy and machinery and produce more residuals. The totality of the manufacturing operation could no longer be considered a light industry. Glass making, silvering, and electroplating produce residuals which need to be controlled.

The primary residuals produced from the glass making operation are air pollutants. They are generally the products of combustion and vaporization. Certain of these pollutants must be reduced by the use of scrubbers, bag houses, venturi cyclones, or elctrostatic precipitors; the pollutants include sulfur oxides, nitrous oxides, organics, hydrogen fluoride, hydrogen chloride, carbon monoxide and particulates.

Electroplating produces both liquid residuals and airborne materials.

During the cleaning and electroplating operations, vapors and mist are generated which must be controlled for the safety of workers and for air pollution standards. Mist or vapors originate from hydrochloric acid, alkaline solutions, nickel sulfate and chromic acid. These vapors must be vented out of the building or collected in a liquid solution. Liquid wastes generated from electroplating must also be treated to avoid pollution. The detoxification, chemical reduction, neutralizing and metal recovery operations require that a waste water treatment system be installed at the plant site. The effluent from this plant will need to meet the strict water pollution control standards set by the Environmental Protection Agency.

The silvering operations have few residuals that contaminate the air. However, some minor treatment of the liquids and overspray is required to either neutralize the liquids or remove silver or copper from the waste water. Ammonia fumes are the main contaminant of air in this process. Venting the fumes is the usual procedure. The liquid residuals from this process originate with the cleaning solutions, stannous fluoride and overspray from the chemicals.

Plastic forming has few residuals. During the mixing of the compound and the molding process vapors are released into the air. This necessitates an exhaust system to reduce any harmful effects to the workers. There are no liquid residuals associated with this process besides the insignificant amounts which may occur due to spills.

CONCLUSION

The findings and projections of this preliminary characterization of a process heat technology and manufacturing plant for the year 2000 indicate that the technology and the manufacturing would be more sophisticated and expanded than exists in the solar industry today. The solar process heat technology is defined to be a parabolic trough collector system and to utilize a combination of the more advanced materials and components under current development. The manufacturing operations are projected to include glass-making, silvering, electroplating and plastic-forming. These integrated operations for the year 2000 solar facility will introduce important environmental residuals which will need to be managed and controlled to satisfy local, state and federal environmental standards. It can be anticipated that the development and growth of the solar manufacturing industry across the nation can produce a shift in both economic activity and environmental impacts to the centers of solar energy utilization.

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IMPLICATIONS OF MEETING THE DOMESTIC POLICY REVIEW'S GOAL FOR SOLAR INDUSTRIAL PROCESS HEAT IN THE YEAR 2000

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ABSTRACT

The DPR has concluded that 2.6 quads of fossil fuel can be displaced by solar agricultural and industrial process heat (AIPH) systems. A requirements analysis conducted by The MITRE Corporation indicates that to meet this goal the federal government will have to institute a 40% investment tax credit, a large field testing and information dissemination program, and rapidly develop high temperature thermal storage media. Production of collectors will have to reach 635 million square feet in 2000 if the DPR goal is to be met. There is a potential for glass and capital shortages that could inhibit the development of the solar process heat industry and the federal government may have to help eliminate these problems. Meeting the DPR goal is a difficult but not impossible task.

INTRODUCTION

President Carter, in his speech of 20 June, 1979, declared that 20% of domestic energy demand will be met with the use of solar energy technology in the year 2000. The selection of this goal stems directly from the conclusions and recommendations set forth by the Domestic Policy Review of Solar Energy (the DPR). A significant portion of solar energy production will have to be supplied by solar agricultural and industrial process heat (AIPH) systems. The DPR has estimated that solar AIPH systems could displace between .1 and .17 quads of fossil fuel in 1985 and 2.6 quads in the year 2000. This estimate translates into annual production requirements of 165 million square feet of collectors in 1985 and over 750 million square feet in the year 2000.

MITRE's analysis of the DPR estimates is part of the National Plan for the Accelerated Commercialization of Solar Energy (NPAC), which was done for the Office of Conservation and Solar Energy of the Department of Energy. The analysis was originally conducted to specify what actions and events had to take place for solar energy systems to be successfully commercialized by the turn of the century. The work summarized in this paper was a requirements analysis; the 2.6 quad goal for the year 2000 was accepted and the analysis constructed to estimate what had to happen for the goal to be reached.

Assumptions

Technologies included in the analysis were flat plates, evacuated tubes, parabolic troughs, parabolic dishes, central receivers and solar ponds. Cost and performance specifications were taken from Systems Descriptions and Engineering Costs for Solar Related Technologies, V. III and Solar Thermal Repowering, both MITRE Corporation publications.

Market potential was derived from macroenergy demand and price scenarios developed by the DPR. These DPR scenarios determined oil prices for 1985 and 2000 and the amount of energy consumed by each major sector of the economy. Costs for other fuels and electric power were pegged to the world price of oil and were generated in house with review by Brookhaven National Laboratory.

Financial incentives were assumed to be in the range of a 35-40% investment tax credit in 1980, declining to a 20% investment tax credit in 1990. This level of financial incentives is equal to those incorporated into the OPTION II level of incentives used in the original NPAC analysis. Financial parameters and industrial decision criteria were those incorporated into the SPURR model and summarized in A System for Projecting the Utilization of Renewable Resources: SPURR Methodology. A summary of all data sources can be found in Table I.

TABLE I

MAJOR DATA SOURCES

SUBJECT	SOURCE
Technology Definition	DPR
Technology Cost/Performance	MITRE
Fuel Costs	DPR, MITRE, Brookhaven NL
Energy Demand/Price of Oil	DPR
Market Potential	MITRE, Battelle
Regional Analyses	MITRE
Federal Incentives	MITRE, Battelle
Financial Decision Criteria	MITRE, DOE

MARKET PENETRATION ESTIMATES

TABLE II

MARKET PENETRATION ESTIMATES

	1985	2000
Square Feet Installed--$10^6 ft^2$	134	628
Total Installed Capacity--$10^6 ft^2$	361	6620
No. of Systems Installed*	1100-1500	5800-7000
No. of Systems in Operation	3200-4000	60000-70000
Percent of Factories Using Solar	0.2-0.9	12.0-14.5
Fossil Fuel Displaced--10^{15} Btu	.1-.17	2.6
Principal Fuel Displaced	Elec.Pwr.- Propane	Propane Distillate
Annual Sales--10^6 \$1976	1100-1300	6800-8000
Market Shares by Technology		
Line Concentrators	73%	44%
Parabolic Dishes	1%	26%
Evacuated Tubes	13%	10%
Flat Plates	1%	2%
Concentrator or Dish	9%	15%
Tube or Flat Plate	3%	3%

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*Systems are sized between 100,000 ft^2 and 2000,000 ft^2.

TABLE II (Concluded)

	1985	2000
Applications--Market Shares		
Solar Capacity for New Installations	3%	55%
Retrofit of Existing Capacity-Fuel Savers	97%	45%
Regional Market Penetration--Percentage of Solar AIPH Installations		
West South Central	26%	28%
East North Central	17%	18%
South Atlantic	14%	13%
Pacific	12%	11%
Other	31%	30%

Interpretation of the data presented in Table II indicates several important trends that should affect the development of solar industrial process heat technology between now and the year 2000.

- Near term applications will almost exclusively be retrofit applications of fuel savers which do not contain thermal storage capability. This will change over time as the best sites for retrofit applications are used up and as more reliable and cost effective thermal storage allows solar process heat systems to be integrated into the design and construction of new industrial installations.

- Early markets will be for hot water, medium temperature air and steam systems, as is demonstrated by the market dominance of line concentrators and evacuated tubes in 1985. Higher temperature parabolic dish systems begin to become important soon after 1985 and constitute one quarter of the market in the year 2000.

- One quarter of all installations will be in the Southwest, in 1985 and 2000, and over half of all systems will be located in the Sunbelt regions of the south and west; this is due to insolation availability, favorable weather conditions, strong growth in industrial demand and land availability.

FEDERAL ACTIONS

All of the market penetration estimates are predicated on the assumption that the federal government becomes significantly involved in promoting the use of solar AIPH systems. Incentives have to be implemented immediately and a commitment has to be made to maintain some level of subsidies through the turn of the century. MITRE estimates that a 40% investment tax credit is necessary for solar industrial process heat systems to be competitive only with the most expensive applications of competing fuels (electricity, propane). Learning curve experience and the economies of scale associated with mass production are expected to reduce system costs using increasingly expensive fossil fuels. For this reason incentives are gradually reduced, 2 percentage points a year, to a permanent 20% investment tax credit as of 1990.

It also will be necessary for federal government to set up a solar industrial loan bank or fund to grant low interest, long term loans to small and medium sized companies. These loans would be constructed to generate positive cash flow within the first three years of operation of a solar process heat system. Tax credits in particular and subsidies in general are by far the most important ingredients to a successful federal commercialization program; two other major efforts, however will have to be launched immediately if the DPR goal is to be reached.

The federal research and development program for high temperature thermal storage must be expanded. As can be seen in Table II, virtually all installations in 1985 are retrofit applications of fuel savers that have no storage capability; by the year 2000, more than half of the installations are integral parts of new capacity and contain significant amounts of storage capacity. If there is not a major breakthrough in storage technology leading to the development of cost effective, high temperature storage media by 1990, the market potential for solar process heat systems will be halved and the 2.6 quad goal set forth by DPR unattainable. Present federal funding for high temperature thermal storage is budgeted for only 39 million dollars over the next five years, and it does not seem possible that this level of funding can assure the rapid development necessary to make storage reliable and cost-effective. A larger federal effort is needed, with a three to five fold increase in funding for FY81-FY87.

As federal incentives make solar economically competitive with conventional industrial energy supply systems, there will still be a large degree of uncertainty concerning the reliability and performance of the technology. The MITRE analysis assumed a large, well funded field testing program that would test solar process heat systems in all areas of the country and provide the data necessary for industry to make a rational decision concerning the performance of the technology. These field testing programs must operate the way industry operates; contracts for systems should be awarded on a $MMBtu of delivered energy basis. The field tests should be cost shared by industrial users and final design specifications should be left to the discretion of the user and the manufacturer, although general categories of systems, such as middle temperature steam, low temperature water, etc., could be specified. Data from the field tests would be used by local Regional Solar Energy Centers and distributed to industry across the country. In addition to the distribution of this information, a large amount of plant visits and audits will have to be conducted to contact and supply data to plant managers and corporate energy officials between 1980 and 1990.

INDUSTRY DEVELOPMENT

The solar process heat industry will have to grow very rapidly in order to satisfy demand for 135 million square feet in 1985 and 628 million square feet in the year 2000. Achieving this level of production in 1985 is an almost impossible task. Production capacity will have to grow 250% per year through 1985 in order to meet projected demand. Expansion of production capacity at so rapid a rate is unprecedented in peace time. However, in order to satisfy projected demand for over 600 million square feet in the year 2000, production capacity will have to expand at a rate of only 10-13% per year from 1985-2000. The difference in requisite capacity expansion for the two time periods indicates some slippage may occur in meeting the 1985 goals without jeopardizing the long range target of 2.6 quads or approximately 6-7 billion square feet installed by the year 2000.

There are, at present, no barriers to entry to the industry, capital costs for production facilities are low (on the order of 10-40% of first year production costs) and there are a large number of firms currently interested in entering the industry. Although solar hardware is material intensive, the fabrication of solar equipment is considered to be light manufacturing, and less capital intensive than many other industries, such as glass and paper, that in the past have achieved high growth rates.

It has been suggested that a truly large solar commercialization program will put a severe strain on materials suppliers in the United States, such as copper smelters, aluminum smelters and glass refractories. MITRE found only two problem areas; the availability of float glass for heliostat production, something only marginally effecting the growth of the solar AIPH industry, and the availability of flat glass. If the DPR goals for all technologies are met in the year 2000, demand for flat glass by the solar industry in that year will equal current (1978) flat glass production capacity. Substitution effects and natural industry growth could mitigate this problem well before a strain is put on existing flat glass capacity. However, it would be appropriate for the federal government to prepare policy options and initiate appropriate action should glass shortages occur.

MITRE assumed no constraint in materials supplies and only historical inflation rates were used to calculate future costs of these materials; any severe constraints on supply will boost the price of the material and the solar equipment and change the market penetration of the technology, perhaps significantly.

Capital requirements are large, between 50 to 70 billion dollars over the next twenty years (in constant, 1976 dollars). The analysis conducted to date indicates that while this amount of capital could be generated by the industrial sector, the effect on the economy could be negative in the short run, with benefits accruing a few years after the turn of the century. In the year 2000, industry will have to spend between 7 and 8 billion dollars on solar energy equipment. Federal tax credits will supply 20% of this, reducing the need for capital to between 5.5 and 6.0 billion. Current expenditures for new plant and capital equipment are between 45 and 50 billion dollars. Assuming a 2% real growth rate, these expenditures will grow to roughly 70 billion dollars in the year 2000. A solar expenditure of 6-7 billion dollars in that year will represent 8-10% of total expenditures, a large but not unmanageable sum. However, should the availability of capital become a problem in the late 1980's or early 1990's the federal government will have to supply credit for the industrial purchase of solar equipment.

SOLAR SUPPLEMENT TO LAUNDRY DRYING

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ABSTRACT

A project was undertaken to develop and demonstrate solar energy used for commercial-scale laundry drying. Air is heated in flat-plate solar collectors and then supplied directly to the air intake of a standard commercial drying unit. The site chosen for this project was the Fort Collins city hospital laundry. The facility is two years old with an excellent layout for a solar retrofit installation. The dryers are next to a south wall and the southern exposure is unobscured most of the day. The collector area is 440 ft^2 (41 m^2). The solar heated air is carried directly to the air intake of the natural gas-fired dryer and the gas burner atop the dryer serves as supplemental energy when solar availability is too low. A short-term pebble-bed storage is provided to store solar heat up to 20 minutes while the dryer is in a cooling cycle and for reloading. The operating procedure of the laundry has not been altered due to the solar system, which has been in operation since Jan. 1979. The study is aimed at determining costs of solar installation, fuel saving, and operational characteristics. Background studies indicate that solar commercial laundry drying has high potential for cost-effectiveness and the CSU project is aimed at demonstration this potential in quantitative terms.

RATIONALE

The cost-effectiveness of solar energy for commercial/institutional laundry drying is favorable due to three factors:

(1) The commercial laundry operates all year and thus utilizes most of the solar energy available on an annual basis. A solar system derives greater value under these conditions because it is primarily an investment cost with very little operating cost.

(2) The commercial laundry is operated during normal daytime working hours, i.e., 7:00 am to 4:00 pm, which is also the period of highest solar availability. Again, the value of the system is increased and the need for solar heat storage is reduced.

(3) The air for drying is drawn from outdoors at ambient temperature. This low temperature air is heated more effectively than is recirculated air, as in space heating.

DESCRIPTION OF FACILITIES

A hospital laundry was selected for this study. It is well suited to a retrofit installation because the heating load (the laundry dryer) is located against the south wall of the building as shown in Fig. 1. The laundry processes 2000-4000 kG of laundry each day and it is dried in three 45 kG natural gas-fired Hurbsch Model 43 dryers. The dryers run through cycles of approximately 1 hour. The actual drying when heat is required lasts for 40 min., followed by 5-10 min. of cool tumbling and 5-10 min. of unloading and reloading. These times are variable and depend on outdoor air temperature, humidity and demand. Under conventional operating conditions, air to the dryer is drawn directly from the building interior space. This air in turn is drawn into the building through a roof hood and tempered with a steam coil heater. A natural gas burner atop each dryer heats the air to the temperature set for drying. Thus the air is heated from two sources, first by the tempering coil to room temperature and then in the dryer itself by direct fired natural gas. Since the hospital laundry does not handle delicate fabric and speed is important, the temperature is set at 95°C (200°F) and the gas burners, which are either off or on full capacity, are normally on. Each dryer has a gas input rating of 67 kW (220,000 Btu/hr) and an air flow rate of 0.8 m^3/s (1700 cfm). Allowing for some loss of efficiency due to site elevation (1500 m, 5200 ft), the unit is capable of heating the room air from 21°C to 100°C (70°F to 200°F).

The operating schedule is quite favorable for solar because the dryers are operated nearly every day. Week-end operation depends upon demand. Also, with only a daytime shift, there is no requirement for storage of solar heat for night time use. Unloading is assisted by a dumping action of the dryer, where the drum swings up 30°, as shown in Fig. 1.

COLLECTOR SIZE AND LOCATION

The space for solar collectors was restrained to fit between two entrance doors to the building and by extension out from the building into a driveway classified as a fire lane. At the optimal year-round collection angle of 45°, this permitted up to 40 m^2 (500 ft^2) of area. Roof mounting was discouraged by the owner over a concern for roof damage. Estimating the peak output at 0.8 kW/m^2 (250 $Btu/hr/ft^2$) of collector area, 84 m^2 (900 ft^2) would be required to meet the demand of a single dryer. Therefore the solar system was sized to meet approximately 50% of the peak load or about 25% of the annual energy requirements of one dryer.

Restrained further by the manufactured collector sizes available, the final selection was 22 parallel collector units each 0.6 m by 3 m (2 ft x 10 ft), for a total of 41 m^2 (440 ft^2). This collector array was installed on a wood frame enclosed structure adjacent to the south wall of the laundry building, as shown in Fig. 2. Solar energy production was anticipated to average 420 MJ/day (400,000 Btu/day) or 28% of the 1500 MJ (1.4 x 10^2 Btu) per day demand for a single dryer. Annual solar energy supplied to the load would consequently approach 160 GJ (150 x 10^6 Btu), depending on the number of days in service.

COLLECTOR SPECIFICATIONS

The collectors are commercially available prefabricated units manufactured in Denver, CO and are single glazed with a black chrome selective absorber surface on copper. Air is passed below the absorber sheet for heating. The back of the collector is insulated with 5 cm (2 in.) thick polyurethane foam in addition to 1 in. of fiberglass insulation. Thermal resistance to back heat loss is 3.43 $m^2 \cdot °K/W$ (20 $ft^2 \cdot hr \cdot °F/Btu$). Collector efficiency from the manufacturer's literature is shown in Fig. 3. This efficiency is given for an air flow rate of 10 $L/s/m^2$ (2 cfm/ft^2) of collector area. Actual air flow is 11 $L/s/m^2$ (2.16 cfm/ft^2).

SYSTEM DESIGN

The system design objectives, consistent with cost, were as follows:
(1) No alteration in present dryer operation
(2) Maximum solar thermal efficiency
(3) Maximum utilization of available solar energy
(4) Minimum electric power for fans

The first consideration was not difficult to comply with. The collector fan delivering air to the dryer is activated from the dryer control calling for heat. The collector air temperature could never be too hot for the fabrics and low availability of solar heat is taken care of by fuel heat in the conventional manner. The duct supply air to the dryer had to be flexible in order to accommodate the swinging dryer drum. This was provided by a neoprene duct with spiral wire for support, as pictured in Fig. 1. There were no alterations of any kind to the drying operation due to the solar installation.

Item 2 pertains to properly designed air flow in the collectors. The same air flow rate which the dryer uses was selected for the solar collectors. This meant that the solar collector air passage had to be sized to provide the optimum velocity of air through the collector, high enough to provide good convection heat transfer from the absorber plate (item 2) but low enough to minimize fan power (item 4). The air flow was established as being the same as used in the dryer at 560 L/s (1200 cfm) at atmospheric pressure and 21°C (68°F). The velocity also depends upon the total collector area and the flow pattern within the array.

The flow pattern is simply parallel flow in each of the collector panels and results in a velocity of 2 m/s (400 ft/min) through the air passages. The flow rate yields a pressure drop of 63 mm of water static pressure through the collector, which is a reasonable pressure drop in terms of fan power requirements.

The thermal performance related to air flow is obtained by first considering the development of turbulent flow, which greatly enhances the convection heat transfer coefficient. The Reynolds number based upon plate spacing is $R_e = \rho VL/\mu = 1885$. Turbulent flow exists for aspect ratios (collector length divided by plate spacing) over 0.0021 R_e. For this collector, 0.0021 R_e = 3.9. Since the actual aspect ratio is 120, the flow is well into the turbulent stage.

Item 3 pertains to the utilization factor both daily and annually. The annual utilization is already quite high and the daily utilization is also high owing to the operating schedule in close timing with the solar period. The primary loss of solar utilization occurs due to the 20 min. or more 'down cycle' time for each operating cycle. As much as 1/3 of the available solar energy is lost because the collectors are shut down. Some of this heat is stored within the collector mass and reappears as a temperature spike when the collector is restarted. To capture 'down cycle' solar energy, a small (60 ft^3) pebble heat storage was installed. Figure 4 is a flow diagram of the system showing the duct connections and mechanical components involved.

Air is drawn through the collectors and storage unit in parallel by the solar fan when the dryer calls for heat. This solar heated air is discharged into a sheet metal hood directly over the drying unit (see Fig. 1). The air is balanced to give 2/3 through the collectors and 1/3 through the storage unit. Since the down time, or solar heat storage time, is about 1/3 of the complete cycle time, this proportion is calculated to yield approximately equal air temperatures from storage and collectors. During the down cycle, the solar fan is off and the solar damper is closed.

The storage fan is activated to draw air from the collectors through the storage. Air exits from the storage into the enclosure under the collectors, however it follows a direct path to the collector inlets. Consequently there is recirculation of air in the storage mode. It should be noted that a small amount of heat is withdrawn from this enclosure under the collectors. The side walls are highly absorbing and there is some collector back heat loss. A backdraft damper on the air discharge of the storage unit allows air to by-pass the filter as it exits in the storage mode.

There are three control functions in this system. One, as previously mentioned, is the dryer heat cycle signal taken from the dryer to activate the solar fan and open the solar damper. There are also two thermostat controls. One is a low limit thermostat on the solar fan which permits the fan to come on only when the solar heated air is above a set point, i.e., 10°C (50°F). This is because the gas burners cannot heat air below about 10°C (50°F) up to 90°C (195°F). Under such conditions, or due to solar system shut down for any reason, air is drawn from the building space through passages under the hood. The second thermostat is a differential temperature control sensing temperature difference between collector outlet air and storage bottom temperature. This controls the storage fan and permits storage of heat whenever collector temperatures are above storage temperatures and when the solar fan is not on. There is a relay interlock to prevent storage operation when the solar fan is activated. Storage can occur before or after operating hours, particularly in summer.

MAINTENANCE

Maintenance has been quite low over the nine months of operation. Two maintenance items did develop. The first was that the solar fan extinguished the gas burner pilot light and this was quickly corrected by installing a pilot shield. The other maintenance item was the failure of the storage fan motor and belt drive. The fan has a single shaft bearing and the belt pulley must be mounted inboard on the fan shaft and the belt tension must be loose to avoid stress and deflection of the fan shaft in its mounting. The stress condition apparently occurred and resulted in motor failure. Proper drive adjustment and a rubber motor mounting appear to have corrected this difficulty.

OPERATIONAL RESULTS

The performance study undertaken is to monitor solar heat delivery to a dryer both with and without the use of heat storage. Both modes of operation function properly. Initial data indicate that 30% to 50% of the solar energy received on the collectors is delivered to the dryers. More operating time and more precise air flow measurements are sought to gain more specific data.

ECONOMIC EVALUATION

The solar installation cost \$10,185 (\$221/m^2), excluding engineering design and planning costs. The collectors were installed by a contractor and the equipment and controls were installed by university personnel using \$14/hr as the cost of their time. This total does not cover all costs that would typically occur in a totally commercial installation, such as profits and overhead, however there were several fixed costs or high costs relative to the system size which raised the price per m^2.

Taking a 20 year life with an amortized loan at 10% interest (typical hospital board rate), the investment cost is 11.58% per year. Adding 10% to that for maintenance and operation expenses, the cost is 12.74% per year. Assuming a useful annual heat production of 160 GJ (150 x 10^6 Btu), the cost of solar energy is 2.8¢/kWh (86¢/therm). Natural gas rates for commercial customers in Fort Collins will be 1.27¢/kWh (38¢/therm) in 1980.

CONCLUSIONS

A solar system to provide institutional/commercial laundry drying can be provided to operate efficiently and with no interference with normal operations. The maintenance and operation costs appear to be quite low but, of course, the equipment is all new. An unexpected favorable factor was observed due to a record setting hailstorm in the region on 30 July 1979, which dropped 1.5 to 3.5 inch hailstones. No damage occurred to the collector covers.

The system economics are subject to several assumptions, however it is clear that solar heat in this situation is roughly twice as expensive as currently available fuel energy. The solar cost is not predicted to lower, however the doubling of natural gas prices within the lifetime of the system is a near certainty.

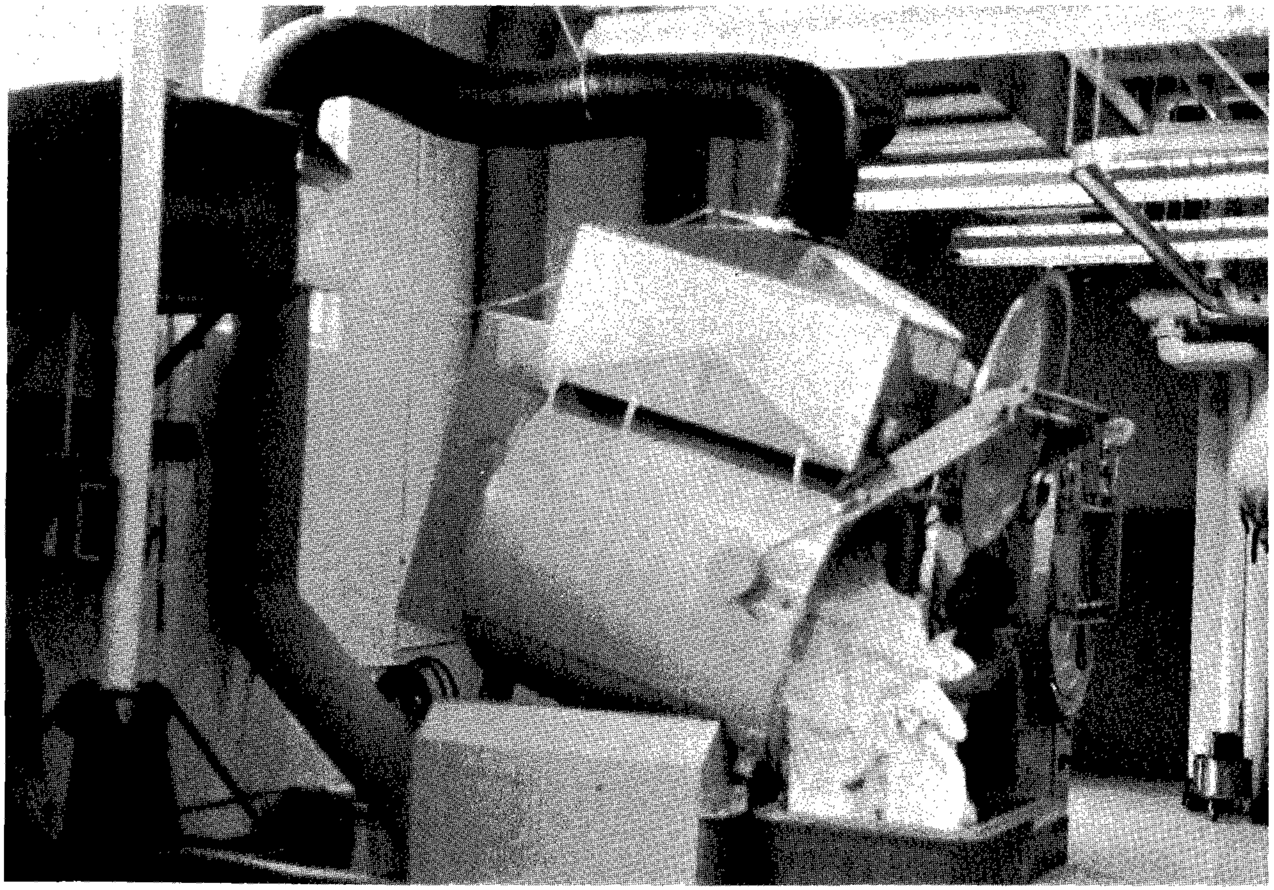

Fig. 1. Laundry Dryer with Solar Addition

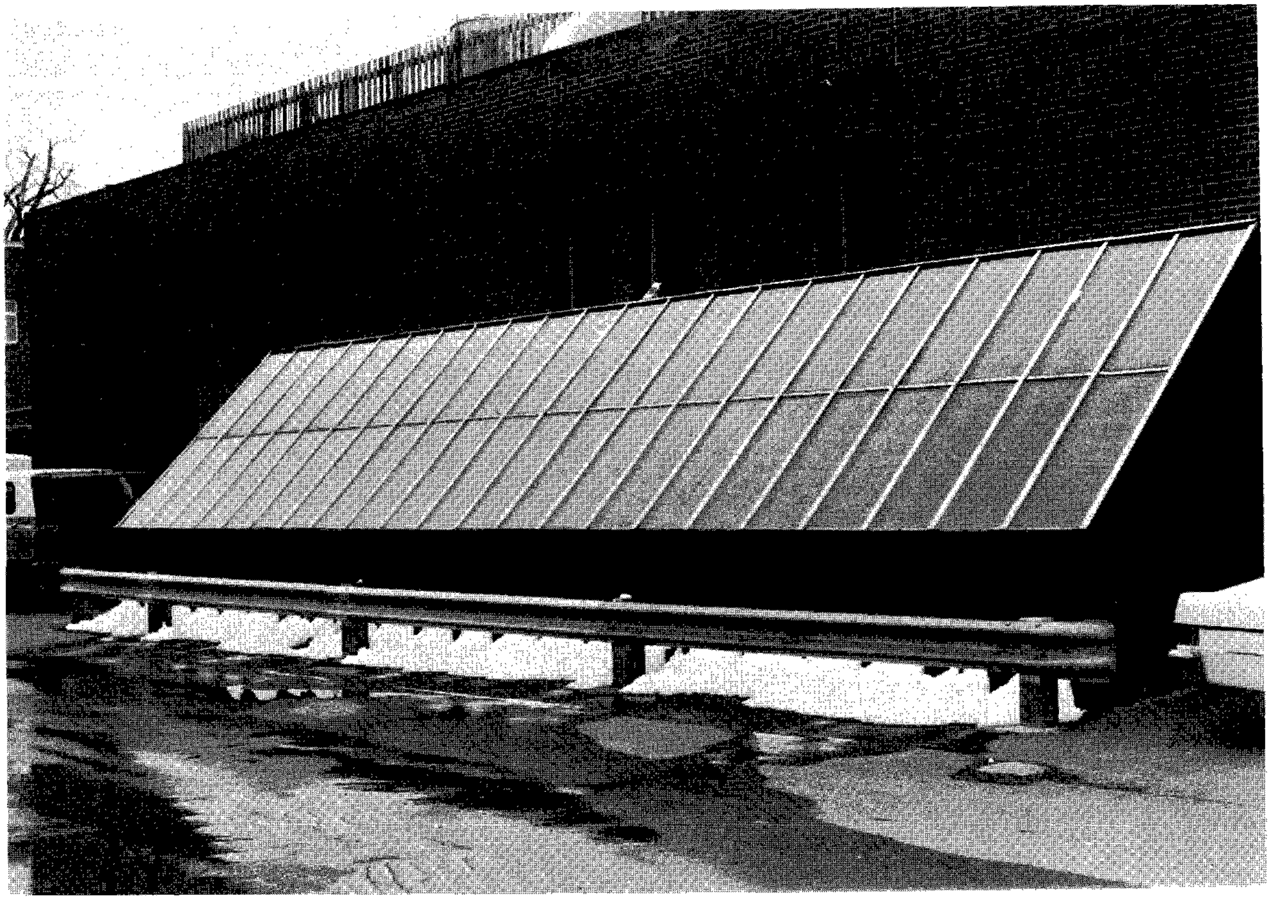

Fig. 2. Air Heating Collectors (41 m^2)

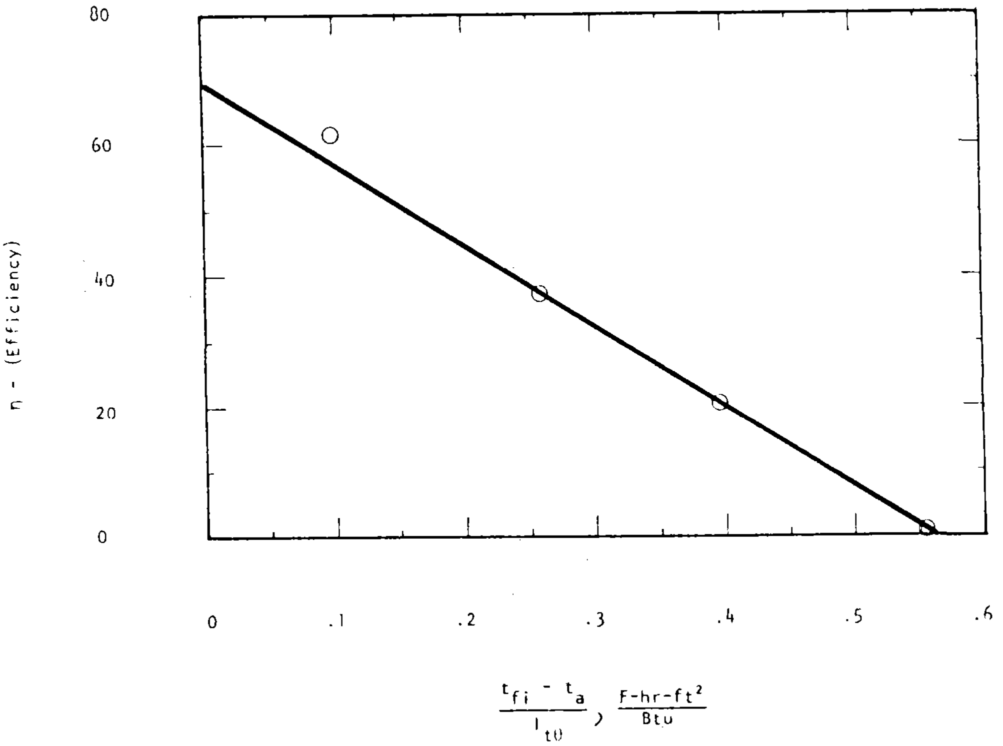

Fig. 3. Collector Efficiency

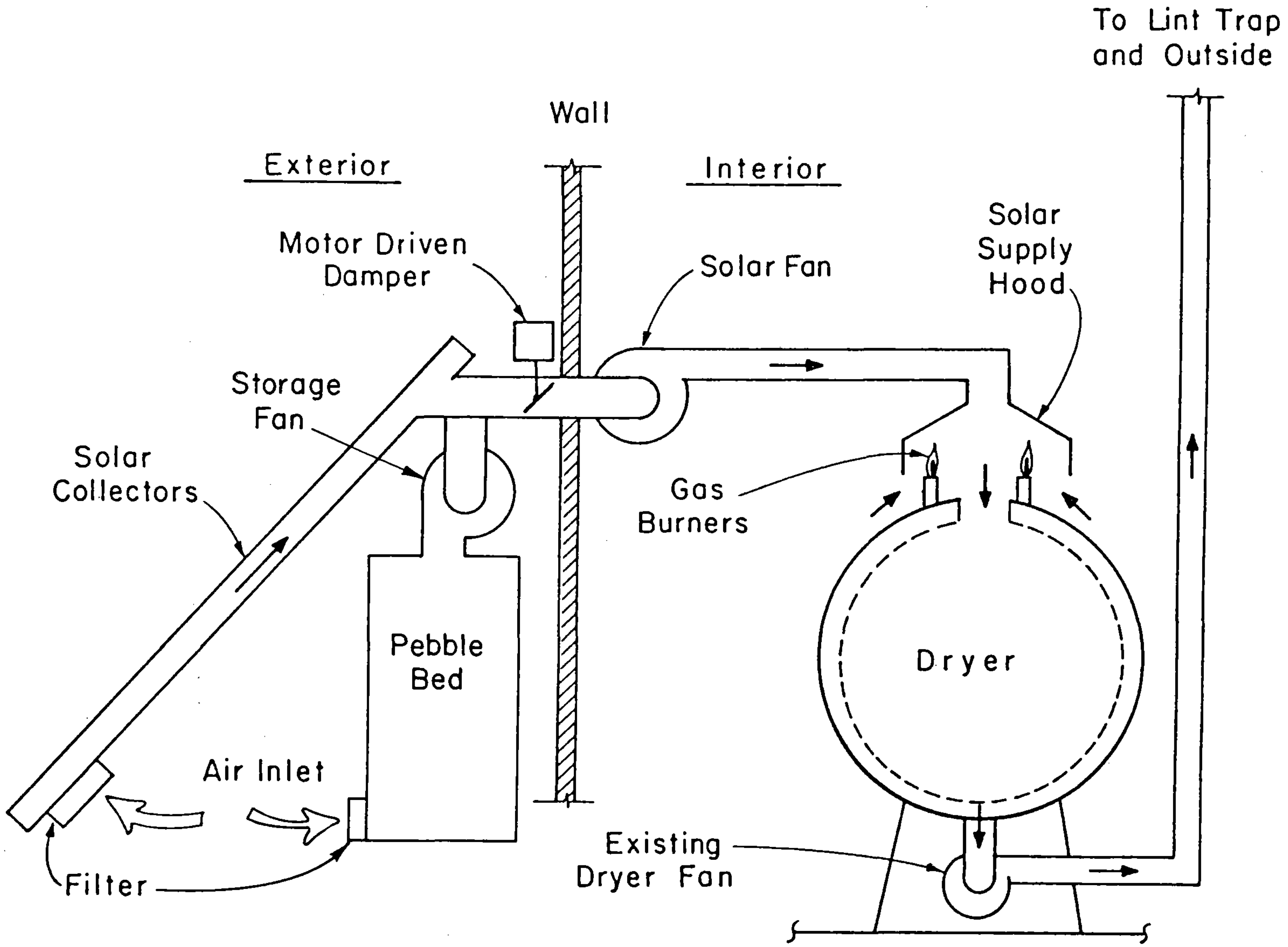

Fig. 4. System Flow Diagram

THE POTENTIAL FOR THE USE OF SOLAR ENERGY IN THE PRODUCTION OF PROCESS HEAT IN ARIZONA

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J. Lobit, ANCO Engineers, Inc., Santa Monica, CA

ABSTRACT

At the University of Arizona, a survey of the potential for the use of solar energy in the production of process heat within the State of Arizona has been performed. The study, conducted for the Arizona Solar Energy Research Commission, examines the technical and economic characteristics of current process heat use within the industrial, commercial, and agricultural sectors of the State and assesses aspects of the feasibility of applications and the extent to which solar energy might displace conventional fuels for this purpose.

Examination of the three sectors has revealed numerous instances in which solar applications appear technically feasible. The economic viability has been found to be strongly influenced by fuel type and availability, duty cycles and application temperature. The greatest single factor in establishment of economic feasibility appears to be the magnitude of Federal and State tax incentives. Follow-on studies to examine the detailed technical and cost/benefit criteria for the identified applications are currently in progress.

GENERAL CHARACTERISTICS OF ENERGY CONSUMPTION IN ARIZONA

Industrial activity in the State of Arizona is not as intensive as in other parts of the country; consequently, the energy demand in the industrial sector is lower than the national average. In 1977 the total energy consumed in Arizona was approximately 70.97×10^4TJ (672.7 Trillion Btu). On the basis of direct conventional fuel use, the industrial sector accounted for only 10% of the total energy use within the State. Figure 1 summarizes the distribution of gross energy consumption by sector for the year 1977.

GENERAL POTENTIAL FOR SOLAR ENERGY IN THE PRIVATE SECTORS

The availability of large amounts of sunshine in the southwest makes Arizona a prime candidate for applications of solar technology beyond residential heating. Of the economic sectors in Arizona in which the conditions for the introduction of solar energy are favorable, the industrial and commercial areas rank highest in terms of the potential for fuel displacement. For moderate temperature thermal applications, solar technology is sufficiently developed to be technically feasible. Within the industrial and commercial sectors and, to a lesser degree for agricultural applications, appropriate temperatures and demands exist. Furthermore, the tax incentives at the State and Federal level significantly contribute to the achievement of reasonable economic pay-back periods. This fact makes it possible, in certain cases, to satisfy the very short (2 to 3 years) pay-back periods traditionally required in a commercial setting.

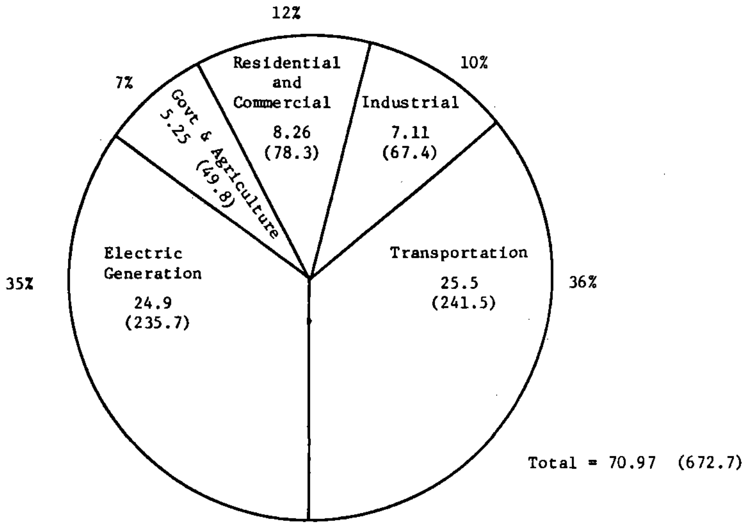

Figure 1 Distribution of Arizona Gross Energy Input by End Use Sector in 10^4 TJ (10^{12} Btu) for 1977

Source: 1977 Arizona Energy Flow, Office of the Governor

In an Arizona commercial setting, with tax credits, solar process heat is competitive with some applications of electric heat and to a more limited extent oil and natural gas. Our analyses [1] indicate that within Arizona's economic environment, flat plate collectors delivering fluid temperatures at 333.15°K-338.7°K (140°F-150°F) can be competitive with thermal energy produced through the use of oil and natural gas. Assuming electric energy costs of 4.5¢/kw-hr, solar thermal energy can be produced competitively to approximately 366.5°K (200°F) assuming employment of selective surfaces and double glazing. In the 366.5°K to 449.8°K (200°F-350°F) range, concentrating collectors may be cost effective but were not examined in this study. Figure 2 shows the cost of delivered solar energy as a function of temperature and collector type under Arizona economic conditions and no tax credits. Figure 3 demonstrates the impact of tax credits on delivered energy costs. Table 1 specifies some of the assumptions used in the collector analyses.

Without regard to the technical and economic considerations of retrofit applications, the total potential for fuel displacement in processes under 449.8°K (350°F) is about 2 million barrels of oil equivalent per year. However, most of the thermal process heat in Arizona is now supplied by low cost oil and gas; only a small fraction, possibly 20% to 30%, of this energy is applied at temperatures below the 338.7°K (150°F) required to compete with current conventional fuel costs.

SECTORAL APPLICATIONS OF SOLAR ENERGY

Industrial Sector

The largest uses of energy for industrial purposes in Arizona are for copper mining, refining and processing. Seventy percent of the energy consumed within the sector is used by the copper industry. While most of this energy is consumed in non-thermal operations, there appears to be some low-temperature applications for solar energy. In particular, the heating of solutions during electrolytic refining, and the drying of concentrate from the flotation process appear viable. Our study found that approximately 3% of all low temperature thermal energy used in industrial operations in Arizona is in two plants in which electrolytic refining is practiced. A new process of hydro-metallurgical extraction of copper also shows some potential for solar applications in solution heating and evaporation [2].

Other significant industrial thermal energy uses occur within the stone clay and glass industry (8% of industrial energy use) and food and kindred products (3%). The development of collectors producing process steam could significantly impact industrial energy use.

Commercial Sector

Within the commercial sector, hotels, commercial laundries and hospitals are potential candidates for economically competitive hot water heating. We have estimated that 20% of hotel energy requirements are devoted to satisfying the demands of domestic hot water heating. Hospitals follow a similar assessment; a new hospital (100 beds) in Tucson supplies all of its hot water heating by solar collection.

While the Statewide impact is moderate, process heat temperatures in the commercial sector are low and flat plate collector technology is proven and readily available. Water heating in the commercial sector has been estimated to consume 6.26×10^{3}TJ (5.93×10^{12}Btu/yr) in Arizona.

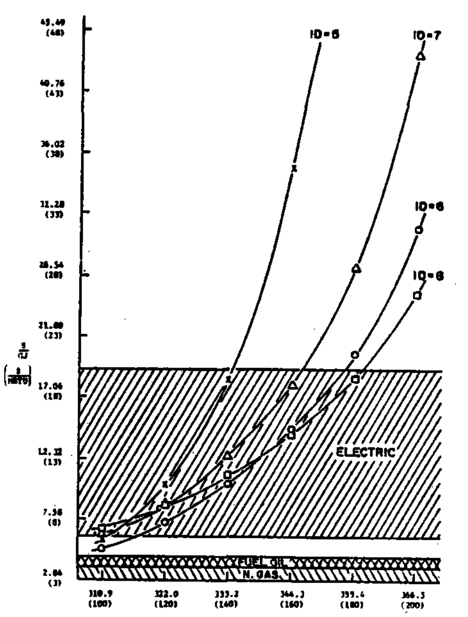

Figure 3 Cost of Delivered Solar Energy as a Function of Collector Input Temperature ETIN: Tax Schedule 2. (no tax credits) (The range of conventional energy costs in Arizona today is shown.)
Note: ETIN (°K) refers to the collector inlet temperature which is reflective of the process temperature requirements; the delivered temperature, however, can be assumed to be ~20° higher.

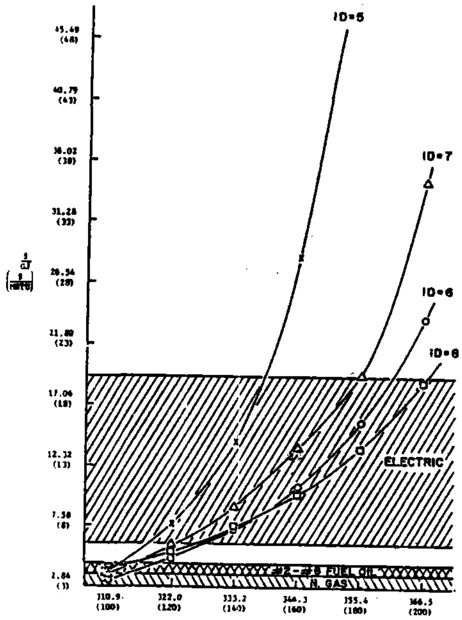

Figure 2 Cost of Delivered Solar Energy as a Function of Collector Input Temperature ETIN: Tax Schedule 1. (with tax credits) (The range of conventional energy costs in Arizona today is shown.)
Note: ETIN (°K) refers to the collector inlet temperature which is reflective of the process temperature requirements; the delivered temperature, however, can be assumed to be ~20°K higher.

TABLE 1 INPUT PARAMETERS TO SPECIFIC COLLECTOR ANALYSES

1. Colector Area = 504 sq. ft.
2. South facing, varying tilt angles with respect to month of the year.

Jan - 45°	Feb - 45°	Nov - 45°	Dec - 45°
Mar - 30°	Apr - 30°	Sep - 30°	Oct - 30°
May - 15°	Jun - 15°	Jul - 15°	Aug - 15°

3. Tax Credits:

Schedule 1	Schedule 2
10% Federal Investment Credit 10% Federal Energy Investment Credit 35% State Energy Investment Credit	No tax credits

Other Assumptions

a. 1% per year thermal degradation in collector performance.
b. 15 year collector lifetime.
c. 10% down payment of original system cost.
d. 10% annual interest rate on mortgage loan.
e. 10% nominal market discount rate.
f. 2% of original system cost for yearly maintenance and insurance.
g. 7% general inflation rate.
h. Electrical energy cost = 4½ ¢/kwhr ($12.16/MBtu).
i. 10% year inflation rate in electrical energy cost.
j. 40% effective Federal-State tax rate.
k. Straight line depreciation schedule.

Agricultural Sector

Agriculture in Arizona, as a consolidated business constitutes the third largest industry in the State and as such possesses large impact potential on the States economy. Total energy use in this sector represents only approximately 4% of total State use, and of this, only 5% is thermal. The Statewide potential for fuel displacement through the use of solar energy is seen to be very small. The low to moderate temperature requirements coupled with isolated siting make feedlot and crop drying applications attractive.

CONCLUSIONS

Our study has indicated that solar energy in Arizona is currently competitive with all conventional alternate fuels when process delivery temperatures are less than 327.6°K (130°F(and remains competitive with electrical energy approaching temperatures of 366.5°K (200°F). In all cases, the availability of tax credits and incentives are pivotal in decisions regarding the use of solar systems in new and retrofit plants. In general, economics favors emphasis on applications to new facilities.

ACKNOWLEDGMENT

This study was supported by: Arizona Solar Energy Research Commission, Office of Economic Planning and Development, Arizona Office of the Governor.

REFERENCES

1. Survey and Analysis of Solar Energy Process Heat Opportunities in Arizona, by Rocco Fazzolare, Stephen E. Smith, Leonel P. Campoy, E. Kobla Glakpe, E. Jay Lobit, George V. Mignon. Prepared for the Arizona Solar Energy Research Commission, Office of Economic Planning and Development, Office of the Governor, Phoenix, Arizona, University of Arizona, Arizona, 1979.

2. A Hydrometallurgical Process for the Extraction of Copper, Cypress Metallurgical Process Corp., Paper presented at 1978 ASME Meeting.

PARABOLIC-TROUGH/FLAT-PLATE COLLECTOR PERFORMANCE COMPARISON

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ABSTRACT

Surveys of industrial process energy requirements that may be met by the use of solar systems show that about one-third of all energy applications occur between 150°F and 600°F, and less than 3% occur below 150°F. Performance comparisons have been made between flat-plate collectors of high quality and parabolic-trough collectors of current quality to identify the solar technology with the greatest potential for near-term impact over the temperature range that spans many process heat applications. The results indicate equal performance at temperatures as low as 110°F. Since troughs are already functioning at 600°F, the tentative conclusion is that parabolic troughs may reasonably be used for applications within the identified temperature range.

INTRODUCTION

Surveys and studies sponsored by the US Department of Energy indicate a very large energy demand in the industrial sector of the US economy and, therefore, a potentially large market for the application of industrial process heat solar systems. Figure 1 summarizes one of those studies [1].

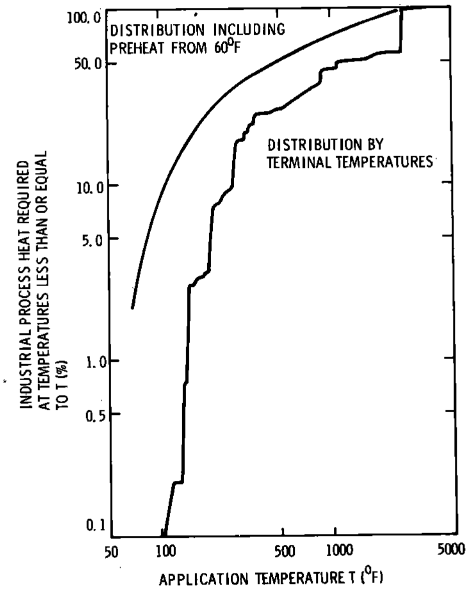

Figure 1.
CUMULATIVE DISTRIBUTION
OF PROCESS HEAT
REQUIREMENTS

As can be seen, approximately one-third of the energy use is at application temperatures of 600°F or below, with about 3% occurring below 150°F. The upper limit of 600°F is selected because it is within the operating temperature range of current technology solar collectors [2].

The purpose of this paper is tentatively to identify the solar technology with the greatest potential for near-term impact over the current technology temperature range of 100° to 600°F.

DISCUSSION

A plethora of solar collectors exists from which to select the technology with the greatest potential for near-term impact. Such a listing includes (but is not limited to) tubular-plastic-film, flat-plate, evacuated-tube, compound-parabolic-curve, fixed-mirror, movable-mirror, Fresnel-concentrator, hemispherical-bowl, and parabolic trough collectors.

The flat-plate collector is probably typical of the nontracking concepts selected by manufacturers to heat buildings in the early government-sponsored solar initiatives. This collector also typifies nontracking concepts that continue to be provided to the private market. Other nontracking concepts are still in a state of basic development.

Of the single axis tracking concepts, the parabolic trough has demonstrated the best performance to date. In general, performances of other collector concepts are expected to fall between flat plates and troughs. Some of the initial results of testing these concepts [2] are shown in Figure 2.

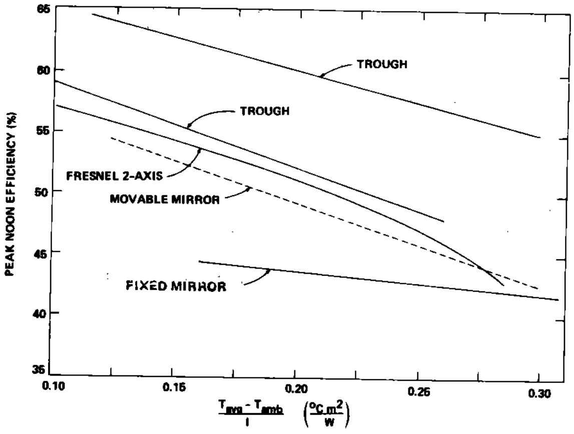

Figure 2. COMPARISON OF SOLAR NOON EFFICIENCY

Collector performance is best compared on an annual basis using measured weather and solar data. Early attempts to select a flat-plate configuration for comparison using such an input resulted in the data shown in Figure 3. At temperatures of interest in the lower end of the temperature spectrum, the one-cover flat plate performed better than the two-cover flat plates. The trough is a better performer at higher temperatures; for this reason single-cover flat-plate collectors were selected for comparison.

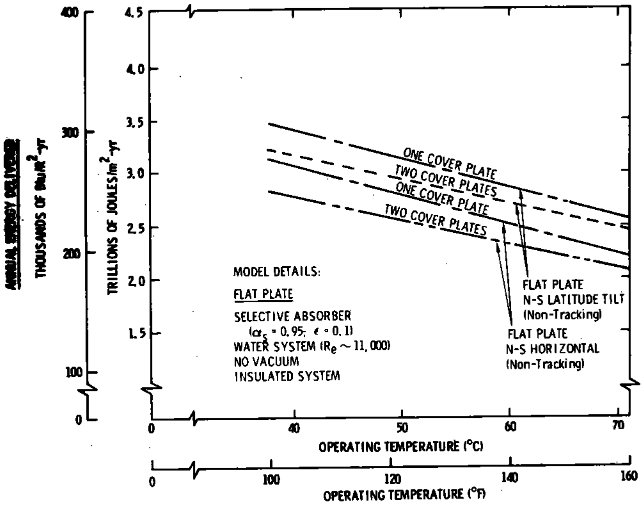

Figure 3.
ANNUAL ANALYTICAL COLLECTOR PERFORMANCE COMPARISONS OF HOURLY MEASURED DIRECT AND TOTAL HORIZONTAL INSULATION, WIND VELOCITY, AND AMBIENT TEMPERATURE FOR ONE- AND TWO-COVER FLAT PLATE, MAYNARD MA (1976)

Since measured direct normal solar data is not generally available, an analysis comparing current technology single-cover flat-plate, and trough collectors was conducted using typical meteorological data for input [3].

A modified version of the SOLSYS [4] code with various collector routines was used for both trough and flat-plate collectors. The trough routine has been experimentally verified at Sandia; the flat-plate routine produced results verified by other companies [3]. The thermooptical properties used for the trough are those of current production materials ($\rho = 0.85$). Those used for the flat plate are better than what is used commercially ($\alpha_s = 0.95$, $\epsilon_{TH} = 0.1$). Recent advances in these properties for the trough indicate that the results are quite conservative; i.e., the trough will perform much better than the results would indicate.

Technology selection is based on cost as well as performance. The presumption is that an approximate cost parity exists for flat plates and troughs so that selection could be reasonably based upon performance comparisons. Surveyed cost data suggest this parity exists [5].

RESULTS

The graphic display best illustrates the results of the comparison. Figure 4 shows the potential annual energy output from a north-south horizontal trough collector as a function of geographical location. (The northeast and northwest sections of the country are not choice solar sites.)

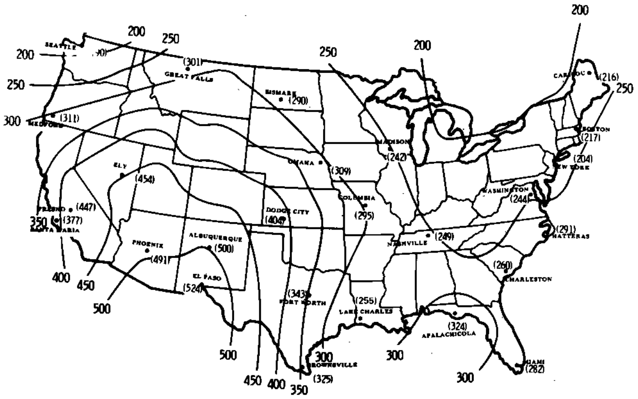

Figure 4.
ANNUAL ENERGY OUTPUT @ 160°F (KBTU/FT^2 YR) AND APPROXIMATE CONTOURS, N-S HORIZONTAL TROUGH COLLECTOR (TYPICAL METEOROLOGICAL YEAR)

Similarly, the potential energy output for a one-cover, latitude-tilted, flat-plate collector is shown in Figure 5. As before, the northeast and northwest sections of the country are not good solar sites.

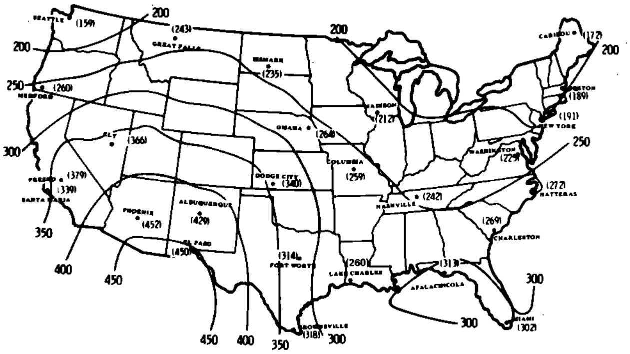

Figure 5.
ANNUAL ENERGY OUTPUT @ 160°F (KBTU/FT^2 YR) AND APPROXIMATE CONTOURS, ONE-COVER LATITUDE-TITLED FLAT-PLATE COLLECTOR (TYPICAL METEOROLOGICAL YEAR)

Contours of breakeven operating temperatures can be determined from the results of the analysis. These contours, displayed in Figure 6, indicate the expected temperatures of operation for equal annual performances of flat-plate and trough collectors.

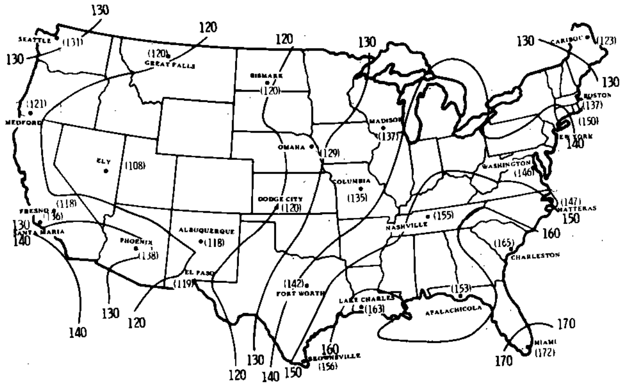

Figure 6.
BREAKEVEN OPERATING TEMPERATURE (°F) AND APPROXIMATE CONTOURS, N-S HORIZONTAL TROUGH VS LATITUDE-TILT FLAT-PLATE COLLECTOR (TYPICAL METEOROLOGICAL YEAR)

CONCLUSIONS

Comparisons of the performances of flat plates and troughs show that troughs are competitive at temperatures as low as 110°F. Troughs are also the best current technology performers at 600°F. Although it is possible for a solar collector type not yet tested to be the best performer within this range, this appears unlikely based upon experiences in testing and analysis.

On the basis of performance and the presumption of cost parity, the tentative conclusion is that the parabolic trough is the best solar technology in the current temperature range of 140°F to 600°F for use in industrial process-heat systems.

REFERENCES

1. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, Inter-Technology Corporation, Vol. I-III, COO/2829-76/1, Warrenton, VA, 1977.

2. Dudley, V.E., Summary Report: Concentrating Solar Collector Test Results, Collector Module Test Facility, SAND78-0815 (Albuquerque: Sandia Laboratories, May 1978).

3. Treadwell, G.W., Low-Temperature Performance Comparisons of Parabolic-Trough and Flat-Plate Collectors Based on Typical Meteorological Year Data, SAND78-0965 (Albuquerque: Sandia Laboratories, February 1979).

4. Edenburn, M.E. and Grandjean, N.R., Energy System Simulation Computer Program--SOLSYS, SAND75-0048 (Albuquerque: Sandia Laboratories, June 1975).

5. Randall, D.E., Personal Communication, August 1979.

CENTRAL RECEIVER SOLAR ENERGY SYSTEM FOR AN OIL REFINERY

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ABSTRACT

The paper discusses the conceptual design and economics of a central receiver solar energy system for an oil refinery scheduled to be in operation by 1983. The system will be designed to make maximum use of existing solar thermal technology consistent with existing refinery design and operating techniques, will provide for the best possible economics for the application, and will offer the best combination of solar and fossil-fuel energy. The baseline system design consists of a tower-mounted, natural-circulation water/steam receiver with a capacity of 18.4 kg/s (146,000 lb/h). A flat-panel absorber generates saturated steam that is superheated to the desired temperature in a separate, oil-fired superheater prior to admission to the main refinery superheated steam headers. The solar plant will furnish 99.3 GWht (339 x 10^9 Btu) or 20 percent of the annual refinery steam demand and will displace annually about 10.7 dam^3 (67,400 barrels) of the salable residual fuel oil produced by the refinery.

INTRODUCTION

The central receiver solar energy system being designed by Foster Wheeler Development Corporation will provide practical and effective use of solar energy in an oil refinery currently being designed by Foster Wheeler Energy Corporation for the Provident Energy Company. The grass-roots 92.0-dm^3/s (50,000-BPSD) oil refinery will be located in Mobile, Arizona. The area, known as Rainbow Valley, is surrounded by the Estrella Mountains to the north and the Maricopa Mountains to the south and west. The site is only 40 km (25 miles) southwest of Phoenix.

CONCEPTUAL DESIGN

Refinery Components and Energy Requirements

Energy for the plant is supplied by burning a part of the fuel oil produced to generate steam. The maximum refinery steam consumption will be about 31.5 kg/s (250,000 lb/h) and the average about 21.4 kg/s (170,000 lb/h). About 80 percent of this steam will be used at the atmospheric distillation unit, the vacuum flasher, and the fluid catalytic cracking (FCC) unit. The main users of electrical power in the refinery are the atmospheric distillation unit, catalytic reformer, residue desulfurizer, and FCC unit, which together use about 75 percent of the plant electrical load of 12 MW. Whether to generate or purchase electrical power has not yet been decided.

Three boilers will be installed, each generating 15.7 kg/s (125,000 lb/h) of steam at 4.14 MPa-gauge (600 lb/in^{2}g) and 370°C (700°F). Each boiler is sized for approximately 50 percent of the maximum requirement. Normally, all three boilers will operate concurrently, providing about 50-percent hot standby capacity for emergencies. When required, one boiler can be shut down for maintenance or inspection, while the other two operate at full capacity. Steam is also generated in waste-heat boilers that absorb the heat from exothermic reactions in some of the processing units.

Heliostat Subsystem

The heliostat subsystem consists of a 59-acre field of 1274 heliostats, related controls, and necessary power for drive purposes, preferably laid out as a north field, 90-deg sector of a circle. The McDonnell Douglas Astronautics Corporation Second Generation Heliostat has 49 m^2 (527 ft^2) of reflector surface. Twelve mirror modules made of second-surfaced high-transmissivity glass bonded to float glass will provide a total mirror area of 6.24 hm^2 (671,000 ft^2). The heliostat drive motors provide both azimuth and elevation motion; a double linear actuator and drag-link arrangement provide inverted stowing capability. The heliostat controller records cumulative motor revolutions and operates the motors to reduce the motor counts commanded by the heliostat field controller. Each field controller commands up to 32 heliostats.

Receiver Subsystem

The natural-circulation-type baseline receiver absorbs heat in an exposed north-facing flat panel of tangential tubes. The exposed panel is tilted 20 deg from the vertical to face the heliostat field at the optimal angle. Water and steam leaving the tubes of the panel are collected in an upper header from which they are carried by a number of riser tubes to the steam drum. In the drum the steam is separated from the water and discharged as dry saturated steam. The water recirculates through the receiver downcomers, from which it is distributed to the lower panel header by feeder tubes. Feedwater enters the steam drum below the water level. The front face of the panel is painted with a high-absorptance paint, and all pressure-part surfaces that do not absorb heat are insulated to minimize heat loss. The receiver pressure parts are top-supported from a structural steel framework and are free to expand downward.

The free-standing baseline tower, made of structural steel, is approximately 93 m (305 ft) high and is capable of supporting an estimated receiver wet weight of 64.0 Mg (70 tons). The tower will be designed for the local earthquake (Seismic Zone 2), soil, and wind conditions.

Other Components

The superheater is a vertical, up-fired steeple design with a cylindrical furnace about 4.6 m (15 ft) in diameter and 12.8 m (42 ft) high. The furnace is lined with tubing through which the steam passes from bottom to top. The steam then passes to a small convection section located above the furnace for final superheating. Steam leaving the superheater passes directly into the refinery steam main and mixes with the boiler steam. Superheater firing rate is controlled to maintain outlet temperature.

A small amount of thermal storage may be necessary to buffer minor insolation transients and to provide adequate time to ramp the existing fossil-fueled steam genenerators. The study will evaluate the desirability of storage, storage media, and optimum storage capacity.

The control system will be designed to provide stable performance in all operating modes including start-up, shutdown, full solar, intermittent cloudy, nonsolar operation, and transition between modes.

As currently planned, the boilers will be operating during solar operation--but at a very low output. The control system's function is to modulate the boiler output in response to steam header pressure to maintain or vary steam flow in response to refinery demands. Ramp rates of the boilers appear adequate to compensate for possible transients in solar-generated steam production. The firing rate of the superheater will be varied in response to superheater outlet steam temperature to maintain the temperature of the solar-generated steam equal to that of the refinery boiler steam.

Selection Factors and Alternatives

There is more than one alternative for the application of a significant amount of solar energy in a refinery. It can be applied to the generation of steam used for turbine drives of compressors, pumps, blowers, etc.; process heating; and other services; or it can be used to supplement the heating of crude oil that enters the atmospheric crude distillation tower. Both of these applications are common to all refineries and are suitable for retrofit. The base-line application selected is supplementary steam generation. This selection increases the potential for acceptance by refinery operators, since redundant steam-generating capacity already exists, and it is not in the direct line of refinery processing as is the crude distillation unit. The selected baseline application is also, in a comparative sense, state of the art and more familiar to operators. It permits a wide choice of receiver systems and is easily integrated into existing systems.

The receiver is simple in design, reliable, and based on proven technology. High heat-flux densities [>0.8 MW/m^2 (254,000 $Btu/h{\cdot}ft^2$)] can be absorbed. Start-up is direct and uncomplicated--no means of protecting an otherwise uncooled superheater is required.

The superheater is a commercially available item used extensively in refineries and chemical plants. It interfaces easily with the existing boilers because it has low thermal capacitance and is capable of rapid response. Turndown capability is also good, and there is no problem with cyclic service for the relatively low temperatures required in the baseline plant. Because of these factors, the separately fired superheater concept is highly suitable for retrofitting existing plants--a very important consideration in this program.

The other option for superheating is within the superheaters of the existing boilers by mixing the receiver steam with the saturated boiler steam before it enters the superheaters. This approach, however, severely complicates the design of the boilers because the superheaters must be sized to superheat the entire refinery steam demand while the boilers are being fired at a greatly reduced rate. The boilers to be used in the Provident refinery, as well as those in many other refineries, are the inexpensive, shop-assembled, package type that use a standardized design and construction. Incorporation of any of the special features discussed previously will necessitate a special design that will be much more costly.

A water/steam receiver system that delivers superheated steam is easily paralleled with existing boilers without additional heat exchangers. However, it requires a special start-up system and a complicated start-up procedure to protect the superheater section. If the steam generator is a once-through design, protection is accomplished by pumping sufficient feedwater through the evaporator and superheater tubes as the heat absorption is increased. This procedure permits rapid start-up. On the other hand, with a drum-type steam generator, whether natural or forced recirculation, there is no flow through the superheater until steam generation begins. Even after steam flow is established, it must be kept adequate in relation to the heat-flux incident on the superheater tubes to prevent overheating of the tubes. Because plant start-up is nonproductive operating time, it should be held to a minimum. This is even more important in a solar plant where start-up occurs daily. Therefore an automated system is required to maximize the energy going into the thermal capacitance of the receiver as pressure and temperature increases while minimizing the amount of steam drawn off to protect the superheater. Another alternative would be to protect the superheater by passing steam from the existing boilers through it. However, this method would require considerable extra piping between the steam main and the receiver and would also require special controls.

The ability of the fired boilers to respond to changes in solar steam output, such as might be caused by cloud cover, must be considered. Boilers of the type used in the refinery have relatively rapid response rates, about 20 to 25 percent of full load per minute. If this rate is not sufficient to cover anticipated rates of cloud cover, then special provisions must be made. These might include buffer storage or a system to anticipate impending cloud cover and reduce receiver output at a gradual, controlled rate consistent with the ability of the boilers to respond. With a saturated steam receiver, buffer storage can be accommodated by using a steam accumulator and operating the receiver at a pressure higher than the operating pressure of the boilers to provide the required thermal head.

ECONOMICS

Energy Collection

Approximately 99.3 GWht (339 x 10^9 Btu) of energy annually is generated as saturated steam with this baseline conceptual design. Allowing for the oil-fired superheater efficiency of 84 percent and the boiler efficiency of 81 percent, the proposed solar plant furnishes about 20 percent of the annual refinery steam demand and displaces annually about 123.0 GWht (420 x 10^9 Btu) or about 10.7 dam^3 (67,400 barrels) of the salable residual fuel oil produced by the refinery.

Baseline Capital and Operating and Maintenance

Preliminary costs have been projected in 1980 dollars for a first and Nth commercial repowered facility constructed in the image of the Provident refinery. The projections include allocated indirect costs and assume eventual installation of 10 plants per year. The costs cover heliostats, the receiver, the separately fired superheater, the receiver feed pump, the free-standing steel tower, piping, control hardware and software, and rough grading. The projections are based on published second generation (Prototype Heliostat Study) heliostat costs as well as Barstow plant PDR costs and the Small Power System Experiment Study costs parametrically adjusted to reflect design and site variations.

Return on Investment

Assuming fuel oil costs $3.20 per million Btu in 1980, escalating at 9 percent per year thereafter, and assuming that the solar plant begins operation in 1985, the annual fuel cost saving in 1985 will be slightly over $2 million and will increase thereafter by the projected 9 percent per year fuel escalation rate.

The cash outflows associated with the "Nth" commercial solar plant costs were calculated in real (escalated) dollars for the 1985 to 2015 time period, and the resultant return on investment (ROI) based on discounted cash flows was computed to be 19.8 percent. The associated (nondiscounted) payback period is 6 years; the discounted break-even point is 9.2 years, assuming a discount rate of 10 percent. The return on investment for the first commercial solar facility was computed to be 15.2 percent.

CONCLUSIONS

No significant technical problems are apparent that would delay this program. Heliostats and field operation, maintenance, and control will have been amply demonstrated in the Barstow plant by 1982. Current experience with heliostat field operation at the Central Receiver Test Facility in Albuquerque is satisfactory. Thus the selected concept has excellent prospects for being constructed and in operation by 1985.

Contractors

Hot Water

SOLAR PRODUCTION OF INDUSTRIAL PROCESS HOT WATER

W. Niemeyer
Acurex Corporation
Mountain View, CA

CONTRACT:	DE-AC03-76-CS31218
CONTRACTOR:	Acurex Corporation/Alternate Energy Division 485 Clyde Avenue, Mountain View, CA 94042
USER INDUSTRY:	Canning plant, Campbell Soup Company, Sacramento, CA
CONTRACT PERIOD:	3/76 through 12/80
FUNDING:	Phase I Design: $204,284 Phase II Construct: $580,859 Phase III Evaluate: $166,748 Phase III Extension: $197,809
PRINCIPAL INVESTIGATOR:	Bill Niemeyer (415) 964-3200 David P. Swartz Stanley B. Youngblood

Objective

The objective of this project is to demonstrate the technical feasibility and cost-effectiveness of using solar energy to heat water for an industrial process at the Campbell Soup plant in Sacramento, California (see Figure 1). The industrial process is a can washing operation that is part of Campbell's soup production line.

A schematic of the hot water system is shown in Figure 2. The design is simple: water passes through the collector field once, without recirculation. Well water enters the flat plate collectors for preheating, passes through the concentrators for final heating, and is sent to a storage tank. Hot water is pumped from the storage tank to the plant upon demand. Additional heating as required is provided by a steam heat exchanger operating from the plant steam supply.

Key features of the system are:

1) Flat plates are used for preheating in the lower temperature range where they are most efficient. They are installed on existing skylights eliminating the expense of additional structural support. The Acurex Model 3001 concentrators provide final heating in the temperature range where they are most efficient.

2) The storage tank accumulates collector energy when the can lines are inactive and over weekends when the plant is shutdown.

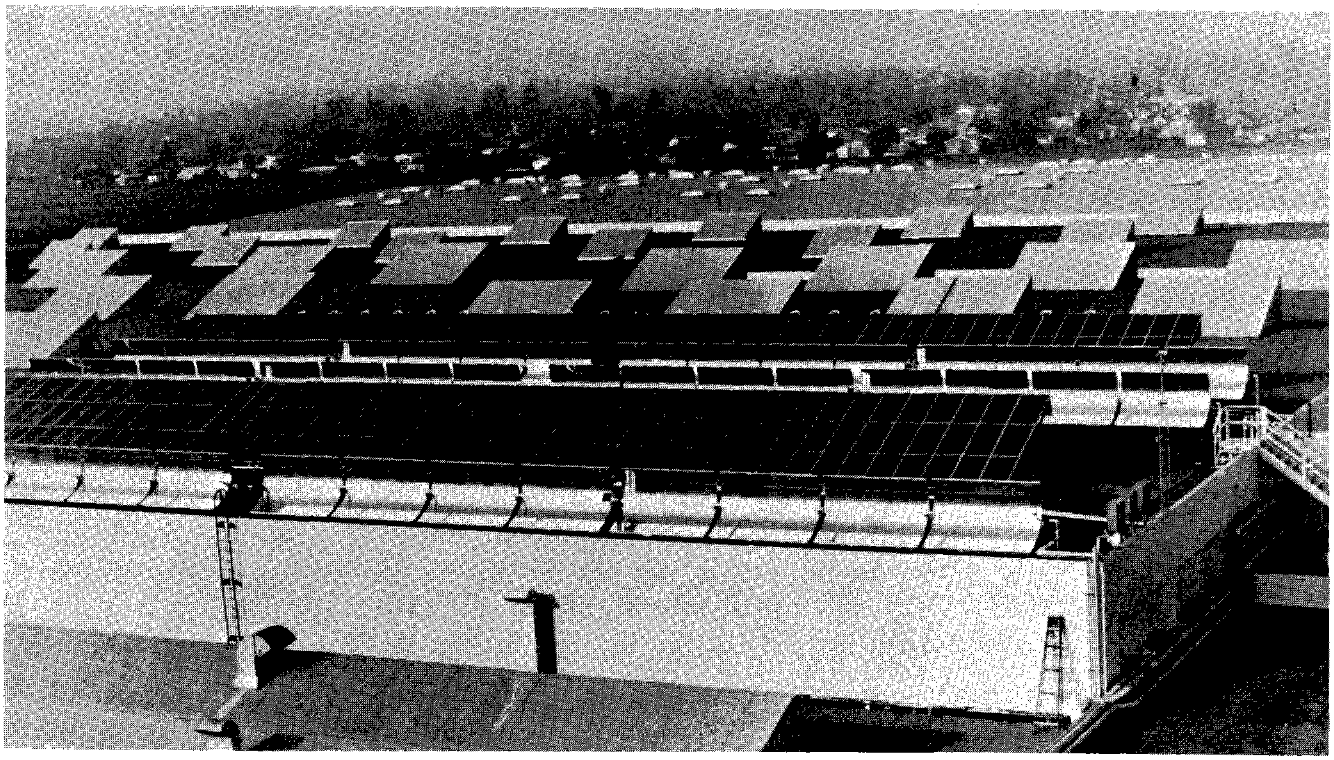

FIGURE 1. CAMPBELL SOUP PLANT IN SACRAMENTO, CALIFORNIA

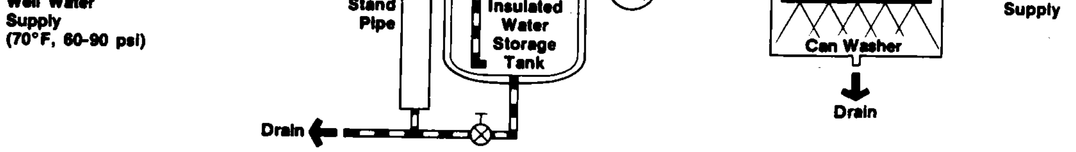

FIGURE 2. CAMPBELL SOUP SOLAR HOT WATER SYSTEM SCHEMATIC

The solar energy system details are:

Collectors:	414 m^2 (4455 ft^2) Solargenics flat plate (inclined 25° to south), single glazed, non-reflective coating
	268 m^2 (2880 ft^2) Acurex Model 3001 line focus parabolic trough concentrators (east/west orientation)
Storage:	64,900 liters (17,150 gallons) working volume
Flowrates:	95 L.P.M. (25 gpm) collector field flowrate
	47 L.P.M. (12.5 gpm) flowrate to can lines
Load Temperature:	345° to 350°K (180° to 195°F)
Control Mode:	Constant flowrate

Status of Project

The solar energy system and data acquisition system are currently in continuous operation and performance data is being collected, reduced, and analyzed. Phase I, Preliminary Design, was begun on March 15, 1976 and completed in October 1976. Phase II, Detailed Design and Construction was completed in December 1977. Phase III, Operation and Analysis, has been extended to December 1980 to provide additional long term performance data.

Various problem areas were discovered and resolved during the construction and operation of the solar energy system. These are listed in Table 1. Based on this experience, Acurex has formulated the following approach to ensure the most cost-effective system designs for IPH applications:

1) The industrial process load should be large and continuous. This will minimize thermal storage and system complexity and maximize the energy supplied by the solar energy system.

2) The solar energy system design should be as simple as possible. This will simplify the process interface and minimize plant interruptions. This will also reduce system costs and enhance operating reliability.

3) Collector field and balance-of-plant design should be standardized to reduce costs for construction, installation, and maintenance.

These approaches have been applied to subsequent IPH solar energy system designs prepared by Acurex and to the current design of the Acurex 3001 parabolic trough concentrating collector.

TABLE 1. PROBLEM AREAS

Problem	Solution	Comment
Wind damage to collectors (severe wind storm in Feb. 1978)	Repair field in-situ	Collector structural rib analyzed and strengthened
High collector field installation costs for retrofit of older plant building	Installed costs are lower for ground installations or new plant construction	Collector design standardized using modular components. Installation costs reduced significantly.
Inadequate water supply pressure	Install boost pump	Supply pressure varies during year, (unknown during design effort)
Two can-line flowmeter damaged by pressure surges	Replace with flow regulator	Regulator maintains constant flow, simplifies data reduction
Digital flow controller valve malfunctioning	Replace with Kates flow control valve	Digital valve could not function with large line pressure surges
Main water supply flowmeter inaccurate	Use Kates valve to measure flowrate (repeatability ± 2%)	Flowmeter was non-repeatable by ± 25%
Data logger, mag tape, malfunction due to excessive heat	Install exhaust fan, replace mag tape	Consider data logger environment
In-situ calibration of RTD's required	Unions installed	Consider during detail design
Rate of water supply to tank non-optimum	Reprogram flowrate sequencer	Anticipate adjustments to system control philosophy
Process load demand not matched to solar supply	Add priority switching to either of two can lines	Batch or cyclic loads complicate system operation

System Performance

The solar energy system and data acquisition system are now in continuous operation and data on system performance is being collected and reduced.

Preliminary analysis of data from the current data collector efforts, started in mid-September, show that the system delivered an average of 6.0×10^6 kJ (5.7×10^6 Btu) per day over a series of clear mid-September days. Average field outlet temperature during these days was 65°C (150°F). These measured values of energy delivered agree in order of magnitude with the values calculated during the preliminary design of 2.32×10^9 kJ/year (2.2×10^9 Btu/year) or 6.4×10^6 kJ/day average (6.1×10^6 Btu/day average).

Future Activities

The planned activities for the project for the next six months are:

- Perform routine maintenance and operation of the system including cleaning, servicing, and maintaining records
- Collect and reduce data bi-weekly
- Analyze and report performance data monthly based on SERI guidelines

SOLAR INDUSTRIAL PROCESS HOT WATER FOR CEMENT BLOCK MANUFACTURE

H. A. Wilkening
AAI Corporation
Baltimore, Md.

ABSTRACT

AAI Corporation is currently engaged in the Operation and Evaluation Period of a contract to design, manufacture, and test a solar assisted hot water system for curing concrete blocks. The collector system consists of 856 meter^2 (9216 ft^2) of AAI's 24/1 concentrating collector. The collectors are mounted on the roof of the new block manufacturing plant near Harrisburg, Pa. owned by York Building Products Co., Inc. Solar heated water is piped to the underground rotoclave or tank in which a circular steel "boat" floats. The heated water cures the green block contained within the slowly rotating boat. Over thirty percent of the curing energy is supplied by the solar system. This system has the potential for supplying energy for the nation's 1200 block plants which consume over a million barrels of oil annually.

PROJECT IDENTIFICATION

The following information is provided relative to Project Identification.

- Project Title - Solar Energy For Cement Block Manufacture
  Contract No. E(04-3) - 1217
- Contracting Organization - DOE/San Francisco
- User Industry - Cement Block Manufacture;
  York Building Products Co. Inc., York,PA.
- Contract Period: April 1976 to June 1980
- Project Funding: Phase I - Design - $114,000
  Phase II - Construction - $449,000
  Phase III - Operation & Evaluation - $100,000
- Principal Investigator - Harold Wilkening
  AAI Corporation
  P.O. Box 6767
  Baltimore, MD 21204
  Phone - (301) 666-1400

OBJECTIVES AND RATIONALE

Objectives

The overall objective of this program is to evaluate the application of solar energy to the generation and supply of industrial process hot water, and to provide an assessment of the economics and resource benefits to be gained. The supply of process hot water for industrial use in the United States requires on the order of 3.1 x 10^{18} joules (3 x 10^{15}BTU) per year which is equivalent to an estimate 4% of the nation's total energy consumption. Due to this widespread use of hot water in industrial processes throughout the nation, the introduction of solar energy in its supply would have a significant beneficial impact.

Rationale

The rationale for picking the concrete block industry was as follows:

- Concrete block curing is an industrial process which uses large quantities of hot water.
- Since concrete block is so basic to the building construction industry and because all concrete block must be cured, the selected process has a widespread need in the industry.
- The manufacture of concrete block is a year-round operation and can make essentially full utilization of the available solar energy. The Rotoclave automated kiln provides a built-in hot water storage capability which allows collection to proceed when the plant is shut down for weekends and holidays.

Potential For Fuel Savings

The potential for fuel savings in the concrete block industry is quite significant. Based on information supplied by the National Concrete Masonry Association, there are 3.5 billion concrete blocks manufactured in the United States each year. For a unit energy requirement for curing of 1.58 x 10^6 joules (1500 BTU) per block, this represents an annual process heat requirement for the industry of 5.54 x 10^{15} joules (5.25 x 10^{12} BTU). Assuming a 70 percent boiler efficiency, this results in a requirement of 1.3 million barrels of oil per year. There is a good possibility that a significant part of this process heat requirement can be economically supplied by solar energy in the future.

PROJECT DESCRIPTION

Plant Description

Figure 1 shows the completed block plant with the solar array installed on the roof. This plant was designed and built during Phase I of the contract, which allowed for a favorable integration of the solar system into the design.

Process Description

The system chosen to manufacture blocks at this facility is called the PACO Rotoclave Automated concrete block plant. The "green" blocks are formed in the block machine and are then transferred by a series of conveyors, elevators and transfer units to the underground circular kiln. The kiln is maintained at an average curing atmosphere of 82.2°C (180°F) and 100% relative humidity. The blocks are allowed to cure for about 12 hours during which time a 14.5Kg. (32 lb) block absorbs 0.32 Kg. (0.7 lbs) of water by hydration. After the blocks are cured for about 8 hours,

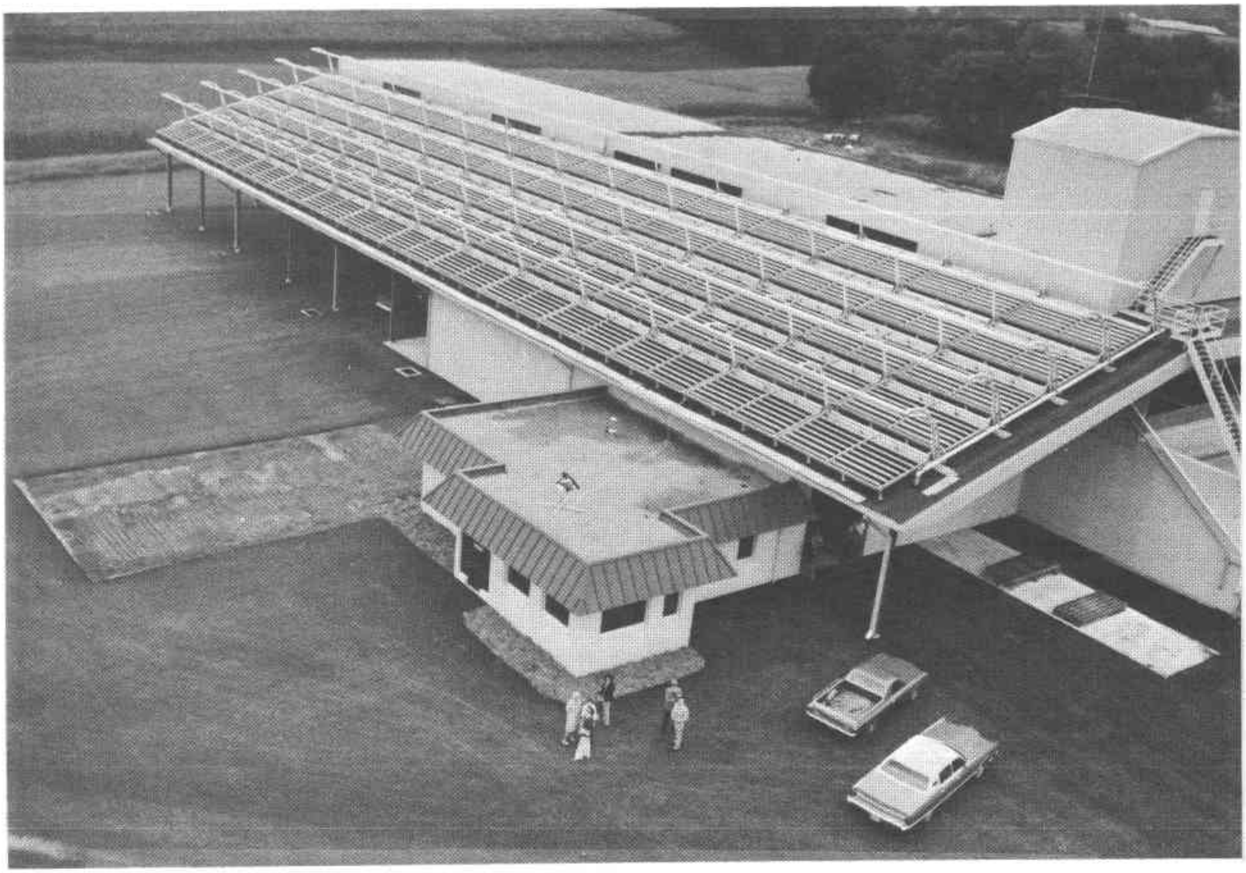

Figure 1
BLOCK PLANT WITH SOLAR SYSTEM

they are withdrawn from the kiln and transferred to the cuber. The cuber stacks the blocks into convenient size cubes on a pallet for handling.

Collector System The solar system selected to supply hot water for this kiln is the AAI Corporation 24/1 concentrating collector. The 856 meter^2 (9216 ft^2) array is mounted on the roof of the block plant as is shown in Figure 2. Thirty-five modular units, 2.7m x 10.2m (9ft. x 34ft.) each are mounted in rows. This collector was chosen for its high performance and associated low weight and durability. The absorber is a single steel tube with a black coating. The concentrator is composed of individual reflectors which are 2.2m (8 ft.) long and 0.3m (1 ft.) wide.

Fluid Loop The fluid distribution system consists of the boiler fluid heat transfer loop and the collector heat transfer loop. A shell/tube type heat exchanger is used in the collector loop. The transport fluid thru the collectors is a mixture of glycol and water to prevent freezing.

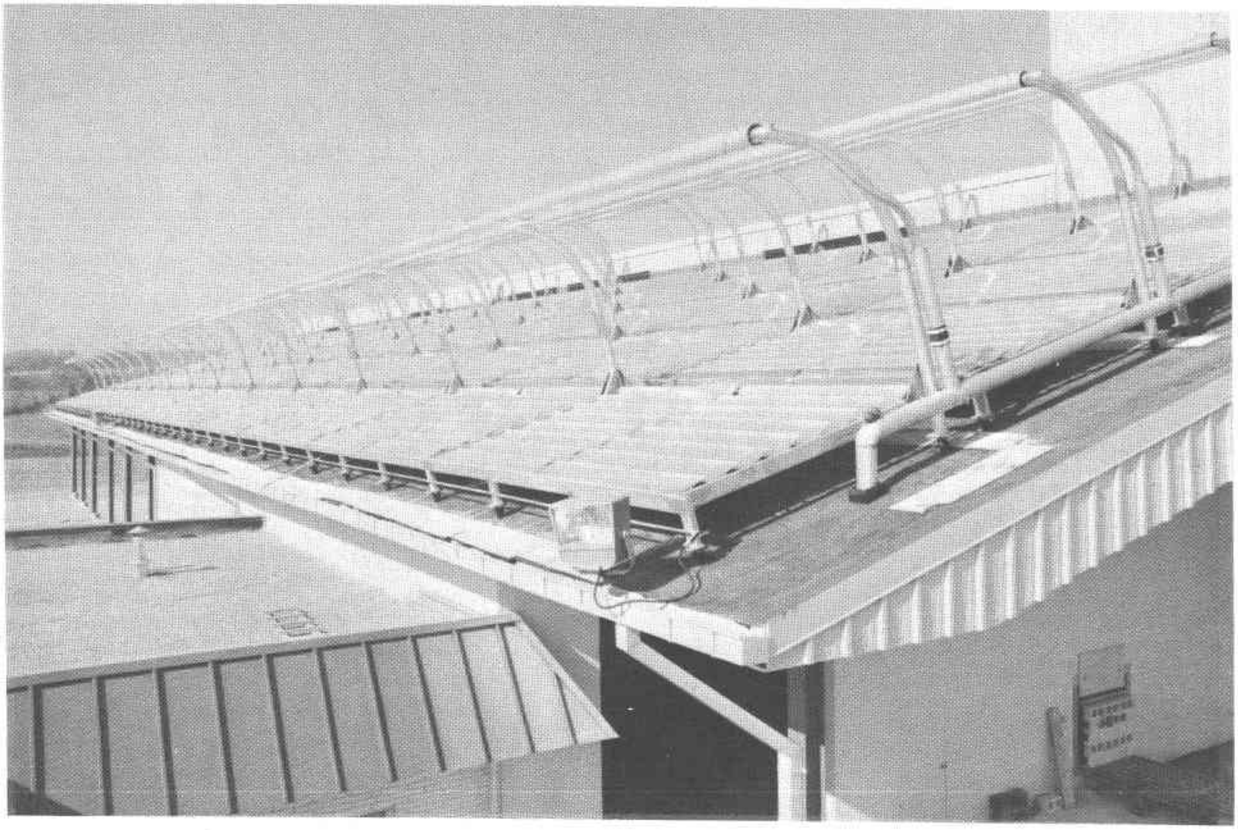

Figure 2
24/1 CONCENTRATING COLLECTOR
INSTALLATION ON BLOCK PLANT

Storage System The thermal storage system is contained in the existing water storage capacity of the rotoclave kiln. The Rotocalve contains 185,850 Kg. (413,000 lbs.) of water. The heat collected on weekends can thus be stored in the rotoclave. The rotoclave has a storage capacity equivalent to raising the temperature of the stored water from the minimum operating temperature of 7.1.°C (160°F) to a maximum of 98.9°C (210°F). This would be adequate for four to five average days of operation.

CURRENT PROJECT STATUS

This project is fully constructed and is now well into the Operation and Evaluation Period which is planned to continue until June of 1980.

PROBLEMS ENCOUNTERED

Failure of Black Chrome Selective Coating

The black chrome selective coating applied to the steel receivers is degrading badly. The design application does not require a glass cover, so the receiver is exposed to the atmosphere, which apparently accelerated this failure. A two coat non-selective coating will be applied to correct this problem.

Thermosiphoning

During the winter of 1978 - 1979, a thermosiphoning condition occurred which brought below freezing water thru the heat exchanger. This caused the water on the tube side of the exchanger to freeze, bursting many of the tubes. The tubes were replaced and flow switches were installed to stop the thermosiphoning. This coming winter will test this arrangement.

DATA ON SYSTEM PERFORMANCE

Anticipated Energy Performance

The 856 meter^2 (9216 ft.^{2}) collector system is expected to produce up to 35% of the energy required to cure cement blocks at this installation. Over 14,000 blocks will be cured per eight hour shift.

The proposed system is particularly efficient since separate water storage is not required. The water in the Rotoclave becomes the storage tank. In addition, solar energy collected on weekends is put into the Rotoclave automatically, allowing it to be used later in the week.

Economic Impact

The economic impact expected for the project is relatively small. It is expected to save about 60 meter^3 (16,000 gallons) of fuel oil per year. However, it is expected to display the potential of the system to the concrete industry. Trade associations like the National Concrete Masonry Association will assist in disseminating information on the project.

Operational Performance

Operational data is being collected by a Fluke Data Logger which records 5 minute data from 20 stations and records it on tape for analysis. Sunny day results show the system is capable of collecting over 7 million BTU's per day. Complete system performance data will be compiled in the Final Report to be submitted in the summer of 1980.

OPERATIONAL EXPERIENCE OF THE LAFRANCE, SOUTH CAROLINA SOLAR PROCESS HOT WATER SYSTEM

J.B. Trice, J. Herz, and R.C. Burns
General Electric Company
King of Prussia, PA

ABSTRACT

Installation of the LaFrance solar process hot water system was completed in June of 1978. Since that time, operation has been continuous, except for several brief periods when the system fluid loop was refilled. During the startup and debugging phase, a number of system modifications were performed which resulted in reliability upgrading.

Several problems with the Data Acquisition System have caused a significant loss in data. From the data available, the overall system performance is below design predictions. While the collector performance is about as predicted, system thermal losses are higher than expected. A number of modifications have been proposed to reduce these losses, and a contract has been awarded by DOE to implement the modification program and to extend the test period.

PROJECT IDENTIFICATION

- Title - Application of Solar Energy to the Supply of Hot Water for Textile Dyeing
- Contract No. - DE-AC03-76CS31220
- Contractor - Advanced Energy Programs
  General Electric Company
  King of Prussia, PA
- User Industry - Riegel Textile Corporation
  LaFrance, SC
- Contract Data -

PHASE	TIME PERIOD	FUNDING $
I - Design & Analysis	April'76-April'77	$258,311
II - Fabrication and Installation	May '77-June '78	610,350
III- System Operation & Data Collection	July '78-Dec '79	147,447

PHASE	TIME PERIOD	FUNDING $
IIIA - System Modifications and Evaluation	Oct '79-Apr '80	$175,082

OBJECTIVE

This project has a dual objective. The near-term objective is to evaluate the application of using solar process hot water for dyeing fabrics. The longer-term goal, in support of the DOE overall objective, is to assess the economic potential for application throughout the textile industry and to promote its utilization.

CURRENT PROJECT STATUS

The LaFrance solar energy system commenced operation on June 15, 1978. Since then, operation has been continuous, except for brief periods when the system fluid loop had to be refilled. During operation, effort has been required to make system adjustments.

A schematic of the system is shown in Figure 1. The major components are identified and location of control sensors and instrumentation is shown.

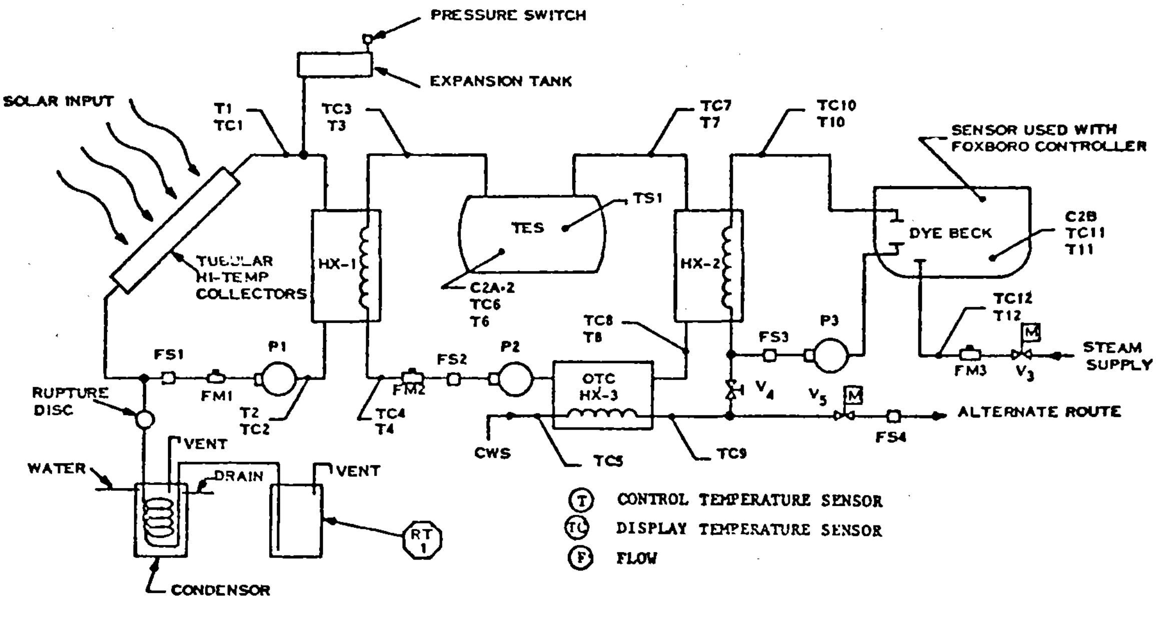

FIGURE 1. SOLAR SYSTEM SCHEMATIC DIAGRAM

Summary of Recent Accomplishments

The system is comprised of 396 General Electric TC-100 vacuum tube collectors. The effective area is 540 square meters (5861 square feet). The thermal energy storage subsystem utilizes water as the storage medium and has a capacity of 30,300 liters (8000 gallons). The solar energy is used in an open 4160 liter (1100 gallon) atmospheric dye beck using dye solution heated to 88°C (190°F).

The system operation was initiated on June 15, 1978 and has operated continuously except for several brief periods when the system loop fluid was refilled. After the initial startup and shakedown phases, data acquisition and analyses commenced. Total system efficiency measurements were made during the operational period. Included in the measurements were insolation and losses in individual subsystems.

The problems encountered and a summary of system data are discussed in the next two sections.

SYSTEM PROBLEM SUMMARY

Several problems occurred during system startup and operation. These are briefly outlined below.

Dye Beck Control Modification

Two problems were encountered (and corrected) with respect to controlling the supply of steam to the dyebeck while at the same time, maintaining the desired balance between the supply of fossil steam and solar heated water. The first problem evolved from the fact that when the dye beck called for heat, both the solar hot water supply and the plant steam turned on simultaneously. The steam injected heat at a much faster rate than did the solar hot water, thus rapidly increasing the dye beck temperature up to the beck shut-off temperature, thereby preventing the solar system from supplying any significant quantity of heat. To correct this imbalance, a time delay was inserted into the control circuitry, so that when the dye beck calls for heat, the solar input is turned on first, followed after a preset time delay by the plant steam input - but only if the temperature of the beck has not increased sufficiently. Thus, the control is now set so that the solar hot water system will supply all of the energy it is capable of providing to the dye beck.

The second problem was caused indirectly by addition of a pneumatic actuator which, upon receiving a signal from the time delay circuit described above, opened the steam valve. The sudden transient pressure drop in the pneumatic line controlling the steam valve, however, was incorrectly interpreted as a signal to close the steam valve. When the pneumatic pressure built up again, the steam valve opened, and the process repeated itself, thus leading to a cycling of the steam valve. Addition of a time delay to allow pressure to build back up in the pneumatic line following the sudden pressure loss has solved the cycling problem.

Pressure Disc Rupture

A pressure relief rupture disc was installed in the collector loop to prevent damage to the hardware that could result from excessive temperature/pressure. In July 1978 the pressure disc ruptured, and the ethylene glycol discharged into the holding tank. The pressure disc was replaced; however, the problem has recurred several times since from various causes of system overtemperature. The basic cause was traced to having set the rupture disc pressure at too low a value. Since then, a relief valve has been placed in the loop to relieve pressure at a somewhat higher setting, and the problem appears to have been solved. Use of the rupture disc has been discontinued.

Pressure Switch Replacement

A pressure switch in the collector loop expansion tank is activated when the pressure falls below a preset value. The purpose of this switch is to turn off the collector loop pump when the pressure falls below the preset value and to prevent the pump from turning back on as long as the loop pressure is low. The intent of inactivating the pump is twofold: (1) to prevent complete loss of the primary fluid to the holding tank following rupture of the burst disc, and (2) to prevent thermal shocking the system with cold fluid when the collectors are at stagnation temperatures. In the event of a slow leak, however, it has been found that as the pressure drops below the pressure switch setting, the switch turns off the primary pump as planned. But subsequently, the pressure builds back up again, since only part of the fluid has escaped from the loop, and the pressure switch turns the primary pump back on. Thermal shock occurs as cooler fluid rushes into the hot collectors that have lost fluid. To prevent this sequence of events and the resultant thermal shock, a temperature sensor has been installed in the collector field to measure an overtemperature condition if it occurs. The field sensor is connected to the control circuitry in order to prevent the primary loop pump from turning on, as long as the loop is too hot.

Collector Field

Collectors are connected to the headers with mechanical tube flare fittings. When the collectors were first installed, 575 of these flare fittings out of a total of 792 leaked. An investigation revealed that during installation, excessive torque was applied to the flares. The installer was shown how to apply less torque, the leaking connectors were reflared, and the problem was solved. Another collector problem involved glass tube breakage. During initial installation, 1% of the glass was broken, due to contractor inexperience. Since that time, more efficient installation procedures have been implemented, and glass breakage during installation has been significantly reduced.

Valve Shutoff

Each of the eleven rows of collectors can be valved off. In early July 1978, four rows were discovered closed. The cause was unknown, but to prevent a recurrence, the valve handles in the collector field have been removed. To date these valves have been required only for test purposes.

Collector Reflector Degradation

Significant reduction in the initial reflectivity has occurred as a result of surface contaminating dust and plant stack effluents. Methodical procedures to maintain initial surface cleanliness have been drawn up and are to be evaluated through tests of washing, sprinkling, and continuing evaluation.

Temperature Switch

Overtemperature control circuitry is actuated by a temperature switch. The switch, however, was observed to be turning on at 110°C (231°F), rather than 121°C (250°F), the design temperature. The switch was adjusted for the higher-temperature setting and has operated satisfactorily since.

Data Acquisition System (DAS)

A number of problems have occurred with the DAS, causing the loss of several weeks of data. A recorder programming error caused all entries to be zero on two different occasions. A circuit board needed replacement on two different occasions. Between diagnosing the problem and obtaining the replacement boards, sixty-one days of data were lost during 1978. Some problems were also encountered with the sensors. One of the steam flow meters, for example, had to be returned to the factory for rework. These problems prevented the continuous accumulation of operational and dye beck energy data.

A number of candidate improvements to the system have the potential of reducing thermal losses so that actual measurements will approach the predicted values. These include cleaning the tubes and reflectors and replacement of insulation for the serpentine and 3/4" headers.

PLANNED ACTIVITIES

A contract to perform the additional work on the LaFrance system and to extend the evaluation period has been negotiated. The proposed work includes incorporating the improvements discussed in the preceding section, re-evaluation of the system performance, and extension of the dye beck tests to one year of operation.

SYSTEM PERFORMANCE SUMMARY

A comparison of predicted and measured performance for the October to December 1978 time period indicated that measured insolation was less than predicted values. Accounting for the lower insolation, collector performance appears to be in the range of predicted values. However, the energy delivered to the dye beck is only about half that initially predicted. This is mainly attributed to line losses and everyday system warmup.

A performance comparison between predictions and measurements is shown in Table 1. Collector aperture energy measured is based on the seasonal data collection and is extrapolated to year-long insolation. The net energy transmitted by Loop #1 is the measured efficiency based on the insolation extrapolated to correct for seasonal changes. The energy reaching the dye beck is estimated to be approximately one-half of the value predicted during initial system design.

TABLE 1. ANNUAL AVERAGE THERMAL ENERGY BALANCE BASED ON DESIGN CALCULATIONS AND PERFORMANCE MEASUREMENTS

LOCATION OF ENERGY FLOW	ENERGY TRANSMITTED THROUGH SYSTEM		
	DESIGN CALCULATION	LAFRANCE MEASUREMENT	COMMENT
Solar Energy into Collector Field	3.16 (100%)	3.16 (100%)	Measured Directly
Thermal Energy Entering Serpentine	1.23 (39%)	0.95 (30%)	Calculated
Thermal Energy Leaving Serpentine (Entering the 3/4" Headers)	1.13 (36%)	0.88 (28%)	Calculated from Heat Loss Data
Thermal Energy Leaving the Collector Field (Entering the 3" Mains)	1.01 (32%)	0.77 (24%)	Calculated from Heat Loss Data
Thermal Energy Leaving the 3" Mains (into the TES Loop)	0.88 (28%)	0.52 (17%)	Measured Directly
Thermal Energy Leaving the TES Loop and Entering the Dye Beck	0.76 (24%)	0.36 (11%)	Calculated

AN ANALYSIS OF THE OPERATION
OF
AN INDUSTRIAL DRYING SOLAR SYSTEM

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ABSTRACT

California Polytechnic State University, San Luis Obispo, under the Industrial Process Division of the Department of Energy, assisted by TRW (Energy Systems Group) of Redondo Beach, and Pacific Gas and Electric Company, has designed (Phase I-ERDA Contract No.E(40-1)-5123), constructed (Phase II-DOE Contract EY-C-05-5123 Mod. A002), and is operating (Phase III-DOE Contract EY-C-05-5123) an industrial hot air raisin and prune drying system at the Lamanuzzi and Pantaleo Drying Plant in Fresno, California. The solar heating system consists of 1951 m^2 (21,000 sq. ft) of solar collectors, a 396 m^2 (14,000 cu. ft.) rock storage facility, and a heat recovery unit. The system was placed in operation during the drying season from August 1978, to mid-January, 1979, and supplied about 80% of the heating requirements for one drying tunnel.

INTRODUCTION

The food drying industry for the last few years has been told to expect a curtailment of the use of natural gas in the future. The date and time has not been set and the general trend of the drying industry is to wait and see. When it becomes necessary for the industry to change fuel or heat sources to stay in business, we will then have their attention. Solar energy and conservation projects will then move ahead. However, until that day comes, the drying industry looks at these projects as an expensive scientific tag with little practical use. When the fires are turned off, this dryer and other projects like it will show what can be done and what the actual costs are.

EVALUATION

The data gathering portion of this project functioned during the entire drying season from August, 1978, to mid-January, 1979. To monitor the performance of the solar system, temperatures, and flow rates were recorded every twenty minutes throughout the season. Also, the gas flow rates for the solar drying tunnel and a control tunnel were recorded at weekly intervals. The totals are shown in Table 1.

The recorded burner use from the monitoring system was low by about 20% because of ambient air peaks around the belts that drive the tunnel fan. With this taken into account, the solar collectors supplied 61%, the remainder of 15% was supplied by the gas fires.

TABLE 1

Total Annual Energy Use

Average Drying Temp.	62°C	143°F
Heat Recovery	3.38 TJ	3202 MBtu
Collectors	1.33 TJ	1261 MBtu
Burners	.71 TJ	677 MBtu
Electrical	84.60 Mw/hr	84601 KW/hr.

Figure 1 shows the weekly energy use through the drying season. The dehydrator operated 7 days a week for the first three months of the year. The later part of October, the plant went on a 5 day a week schedule until the mid-part of January for a total of 133 days of operation.

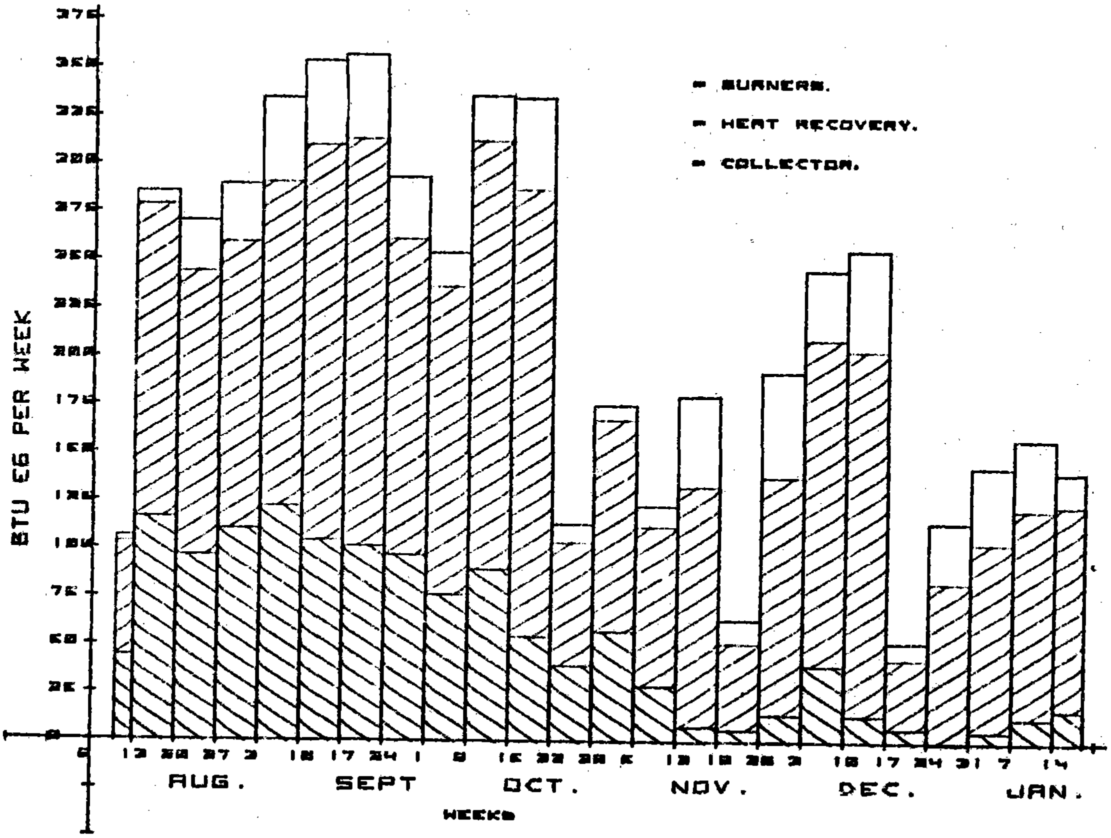


FIGURE 1

Weekly Energy Use From Aug. 1978, to Jan. 1979

Comparison Between Experimental Results and Simulation Model

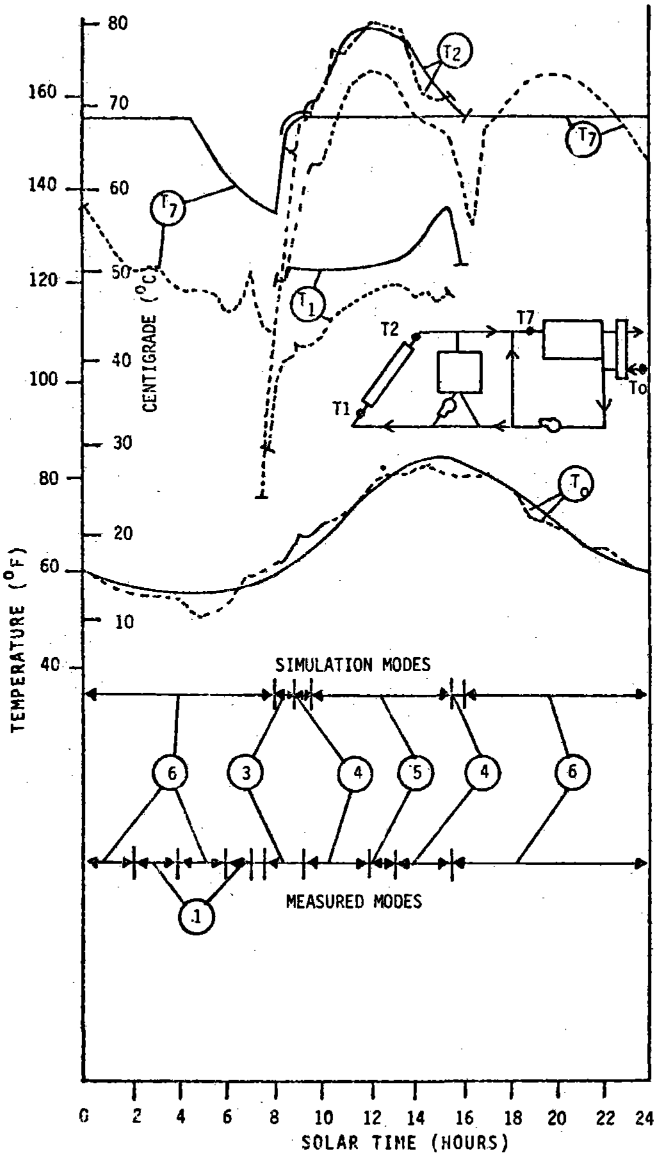
It is of interest to compare system performance predictions based on the computer simulation model developed during the design stage (1) with actual experimental results. The comparison will point out some of the component, system design, and simulation defficiencies that should be corrected in future applications.

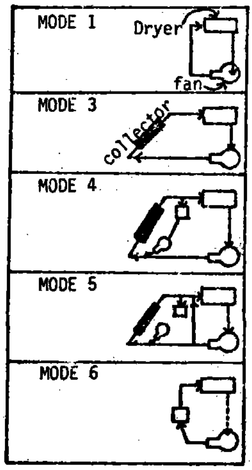
In order to make this assessment, a detailed comparison was made between the experimental data for Sept. 11, 1978, and the simulation results for that date using the actual weather data and tunnel conditions as input. The Sept. 11, date is near the "design day" of Sept. 21, used during the design stage to make system parameter sensitivity studies. Sept. 11, was a clear day, with a measured insolation virtually identical to that predicted by ASHRAE based on simulation algorithm with a clearness number of 1.01. The simulation predicts hourly ambient temperature based on a fixed hourly distribution between the daily low and high. On this date the low and high temperatures of 12.8°C (55°F) and 28°C (83°F) were used in order to simulate the measured conditions. The actual and simulated ambient temperatures, To, are compared in Figure 2.

The simulation assumes a constant air flow rate through the produce tunnel, with the air temperatures entering and leaving at fixed values over the 24 hour operating period. In actual operation the temperatures and flow rate varied, so measured daily average values were used for the simulation input. The daily average measured produce inlet and exhaust temperatures were 68°C (155°F) and 53°C (128°F), with an average flow rate of 430.1 KN/hr (196,700 lb/hr) (15% above the design value). The measured temperatures varied around these averages because of thermostat control inaccuracies, varying produce conditions, tunnel openings, and flow rate variations through the tunnel. The tunnel flow rate varied primarily due to the inability of Fan #1 to supply as much flow during midday conditions (when high system pressure drops are caused by the additional operation of Fan #2) as during less demanding hours. Fan #1 supplied more than the design flow rate of 373.6 KN/hr (84,000 lb/hr) through the tunnel at the midday conditions, and the flow rate variation was due to setting the flow control for too high a tunnel flow rate during this operating day rather than an undersizing of Fan #1.

The simulation also assumes a constant heat recovery effectiveness, where in fact it varied during the day due to the above flow variations. A value of 86% was used in the simulation which was the daily average measured value on Sept. 11, and the same as the manufacturer specified for the 373.6 KN/hr (84,000 lb/hr) (20,000 cfm) design flow rate.

The simualtion modedlled the air collector performance by equations developed and validated previously (1 and 3) but applied here to the installed collector configuration. A number of comparisons between the model predictions and the experimental performance of the installed collectors were reported previously (2). An additional comparison is shown here for the solar noon conditions of Sept. 11. At this time the measured collector operating conditions were as follows:





MODES:

1. Bypass entire system.
3. All product air through collector only.
4. Excess air through collectors maintains T2 = T10.
5. Maximum air through collectors bypass air maintains T7 = T10.
5. All product air through storage.

FIGURE 2
Comparison of Predicted & Actual Results

collector flow	984 Kn/hr	221,300 lb/hr
T inlet	47°C	118.00°F
T outlet	78.8°C	173.90°F
T ambient	25.0°C	77.00°F
Insolation @ 35° collector tilt	3.6 MJ/hrM^2	319 Btu/hr. sq.ft.

For the 1904 m^2 (20,500 sq. ft.) collector aperture area and air specific heat of 0.244 Btu/hr.°F the instantaneous experimental efficiency was

$$\eta = \frac{221,300\ (.244)\ (55.9)}{20,500\ (319)} = 46.2\%.$$

For the same flow rate and ambient conditions the equations of Ref. 2 (which are also incorporated in the simulation) were used to predict the efficiency. The parameters that were used in these equations were as follows (these parameters are defined in Ref. 2):

T_p	average absorber temperature	73.8°C	165°F
T_{sky}	sky temperature at 65°F wet bulb	13.7°C	56.7°F
α_c	absorber absorptivity		0.95
E_1	cover emissivity		0.9
V	wind velocity	4.8 KM/hr	3 mph
C	absorber to cover convection coefficient		0.2
K	factor for fin enhancement		1.3
τ_s	short wave cover trans. at 0 incidence angle		0.85
τ_l	long wave cover trans.		0
U_B	bottom loss coefficient	1696 J/hrM^{2}C°	0.083Btu/ hr. sq.f
d	depth of air channel	.076M	0.25 ft.
dh	hydraulic diameter of air channel	.137M	0.45 ft.

Using these values and the air channel convection coefficient correlation of Ref. 2 for properties evaluated at 63°C (146°F), yielded an efficiency of 47% close to the experimental value.

The thrust of this discussion of measured vs. predicted collector and heat recovery performance is that these components were probably simulated correctly and thus that the disagreements discussed below between the experimental performance of the whole system and the simulation are not thought likely to be attributable to any lack in the performance or simulation of these particular components.

Hourly Comparison Between Measured and Simulated Performance

Figure 2 compared selected measured system temperature with those calculated by the simulation, along with the actual and simulated operating modes that occurred. Independent of any simulation inadequacies, detailed hourly differences were to be expected between the experiment and simulation because the control system as built (2) differs in a number of respects from the control system modelled (1). Although the operating modes were similar, small differences in control logic were incorporated in the final system design. In addition, some ducting and therefore friction loss details don't match between the facility and the simulation. Because the differences were small, no major differences in overall performance were to be expected.

Perhaps the major discrepancy shown in Figure 2, is the mismatch between the measured and predicted temperature T7, the temperature of the air delivered to the tunnel upstream of the burners. During early morning hours the measured T7 values clearly show the storage being depleted long before depletion is approached in the simulation. This discrepancy has been attributed primarily to the apparent inability of Fan #2 to supply sufficient flow through the storage. The measured flow through the storage at solar noon was 618 KN/hr (139,000 lb/hr) compared to 832 KN/hr (187,000 lb/hr) indicated by the simulation. This is low by 213 KN/hr (48,000 lb/hr) or 26%. This measured storage flow was low probably for two reasons. First, because of the higher than design tunnel flow the collector pressure drop at midday was than expected, limiting the ability of Fan #2 to supply its design flow. In addition, the storage pressure drop was measured to be approximately 30% higher than that allowed for in the fan selection, despite the fact that a liberal allowance was made in the design for the possibility of higher than expected storage pressure drops (4).

The 26% lower flow rate during the storage of heat would indicate on the order of 26% less heat being stored. This is corroborated somewhat by integration of the measured hourly temperature and flow rates into storage which indicated 9.92 GJ (9.4 MBtu) were stored during the day which is about 20% lower than that indicated by the simualtion.

That the storage did not fill as much as indicated by the simulation is also shown by the fact that the measured storage bottom temperature never changed significantly during the loading period, whereas the simulated storage bottom temperature was raised to half its potential rise by the end of the loading period. The rapid increase in simulated collector inlet temperature T_1, shown in Figure 2 at 1500 hours shows the effect of this rising storage bottom temperature. The colder storage bottom rock also explains why the measured collector inlet temperature T_1 shown in Figure 2 was much lower than that indicated by the simulation.

Another discrepancy is seen in Figure 2 to occur between the measured and predicted delivery temperatures T7, during the period between 0800 and 2400, where the measured T7 shows larger swings (up to 5.5°C (10°F)) above the set point of 68°C (155°F) than the 2.8°C (5°F) that the control system was intended to allow. This shows some inadequacy of the control system to adjust damper D4 as intended in the design.

The constant value of T7 shown by the simulation model after 1000 on, points out that the simulation model assumed a "perfect" control system without any consideration of possible control instabilities or control drift. It assumes zero control differentials, no permanent offset (droop) between control points and setpoints, and instantaneous damper action, all of which were finite in the installed control system.

Another major discrepancy seen in Figure 2 between the measured and predicted performance is the large difference in temperature during the midday between the collector outlet temperature T2 and the temperature of the air delivered to the tunnel T7. At solar noon these values differ by about 4.5°C (8°F). This difference is attributed to heat losses from the ducting and other system components. A 4.5°C (8°F) drop at the noon flow rate between the storage and tunnel corresponds to about 4.22 GJ/day (4 MBtu/day) loss. This magnitude of loss can be accounted for by conduction through the various systems components and ducts. Heat losses from the ducts were aggravated by the lack of insulation along the bottom of the duct perimeters due to lack of space for spray foam application. Also, uninsulated duct support straps, and rubber collector-to-duct transitions contributed. Although collector and storage wall heat losses were accounted for in the simulation the other components losses were not simulated.

EMBODIED ENERGY ANALYSIS

The primary purpose of the application of solar energy to any industrial process is to displace the use of conventional fuels. It is possible that the energy required to construct and install a new type of energy delivery system could be greater than the energy contained in the conventional fuels which it displaces. To address this question, the amounts of energy embodied in the material used to fabricate this system were identified.

The energy allocation techniques used in this study are taken from data generated by Hannon et. al., (5,6). Two allocation techniques were used, one for basic materials and one for equipment. For the energy embodied in the materials of construction, an allocation per unit of material including an approximation of the energy required to deliver the materials to the job site was used (5). An allocation based on total cost (6) was used to approximate the energy embodied in materials of construction and equipment were determined by the University of Illinois Center for Advanced Computation Energy Input/Output Model as reported in (5) and (6). A list of over 100 material items used to build this system was prepared and the energy embodied in each item computed The totals in each major category are shown in Table 2.

TABLE 2

Energy Embodiment Allocated to Major Construction Categories

Collectors	6.29 TJ	5.96×10^9 Btu
Insulation	2.89 TJ	2.74×10^9 Btu
Fans and Dampers	1.90 TJ	1.80×10^9 Btu
Concrete	1.58 TJ	1.50×10^9 Btu
Heat Recovery	1.08 TJ	1.02×10^9 Btu
Controls	1.05 TJ	1.00×10^9 Btu
Site Preparation	.98 TJ	$.93 \times 10^9$ Btu
Storage	.94 TJ	$.89 \times 10^9$ Btu
Steel, Ducting & Labor	.32 TJ	$.30 \times 10^9$ Btu
TOTAL:	16.99 TJ	16.10×10^9 Btu

The embodied energy per unit cost of this system was found to be 46.4 MJ/dollar (44,000 MBtu/dollar). This represents the amount of additional energy consumed per dollar spent on construction. The value can be compared with 54.9 MJ/dollar (52,100 Btu/dollar) spent on two-to four-family housing and 74.8 MJ/dollar (70,900 Btu/dollar) spent on new industrial buildings. Neither of these constructions displace current sources of energy though.

Since the purpose of building this system is to replace conventional sources of energy, it is important to compare the energy embodied in the system with the amount of solar energy provided by the system. If this ratio were less than unity, the viability of the design should be questioned, or the system redesigned using less energy intensive materials. Considering the total amount of solar heated air supplied to the dehydration tunnel during the six month drying season it was found that the energy embodied in this system will be returned in a period of 4.8 seasons. After that period, it will become a net energy source and will have paid back the original energy investment required to construct it. It can be concluded therefore that this system will produce more energy than was required to build it.

ECONOMIC ANALYSIS

The economic analysis was based on the 1978-1979 performance season totals as shown in Table 1 and agreed within 3.5% of the assumed seasonal heat load from Phase I, design. The system costs were reported in Phase II and were only 7% lower than estimated construction costs from Phase I.

The various construction cost components were apportioned to the three major subsystems installed with the following results:

Collectors	$ 213,285	63.1%
Storage	89,685	26.6%
Heat Recovery	34,810	10.3%
TOTAL:	$ 337,780	100.0%

A life cycle cost analysis as specified by Dickinson and Shearer (7) was performed and is summarized in Table 3. The last two columns of Table 3 show the impact over tne project life of an escalation in energy cost relative to the rest of the economy.

It is certainly clear that the heat recovery unit is an extremely cost effective system component under virtually any realistic economic predicting. The situation with the complete solar system is not so clear. When one compares the embodied energy pay back of 4 to 5 years as compared to an economic payback from 12 to 19 years, depending on the economic variables, assumptions show that the system has potential, but the cost of fossil fuels are far too cheap for solar energy to compete economically.

TABLE 3

Life Cycle Cost

1978 - 1979 ENERGY COSTS						(Adjusted for 5% Differential Fuel & Electrical Inflation)	
PROCESS HEAT SOURCE	NET* INCREMENTAL INITIAL INVESTMENT	FOSSIL FUEL CONSUMED MBTU	ADDITIONAL ELECTRICAL USED KW hr.	SYSTEM COST $ / MBTU BEFORE TAX	PAYBACK PERIOD YEARS	SYSTEM COST $ / MBTU BEFORE TAX	PAYBACK PERIOD YEARS
NATURAL GAS	-0-	5140	-0-	$ 2.80		$ 3.98	
GAS with HEAT RECOVERY	31,329	1938	23,100	2.44	6.81**	2.98	5.01**
SOLAR with HEAT RECOVERY & GAS BACK UP	304,002	678	84,601	12.46	27.92**	12.96	24.06**
FUEL OIL	7***	5140	-0-	5.37		7.56	
OIL with HEAT RECOVERY	31,329***	1938	23,100	3.73	3.73	4.45	2.69
SOLAR with HEAT RECOVERY & OIL BACK UP	304,002***	678	84,610	12.97	18.80	13.61	15.08
SOLAR alone with HEAT RECOVERY ****	304,002	-0-	84,610	13.93			

* Net of 10% investment tax credit

** Against gas fuel

*** Costs of burners, boilers, storage and emission control not included

**** Inadequate for current process operations

ACKNOWLEDGEMENT

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REFERENCES

1. California Polytechnic State University, "Research on the Application of Solar Energy to Industrial Drying or Dehydration Processes", (Final Phase I Report, Design-California Polytechnic State University, San Luis Obispo, California, March, 1977, NTIS, ORO/5123-1, Springfield, Virginia).

2. Ibid. Final Phase II Report, Construction-California Polytechnic State University. San Luis Obispo, California, September, 1978.

3. Niles, P.W., et. al., "Design and Performance of An Air Collector for Industrial Crop Dehydration", Solar Energy, Vol. 20, 1978.

4. Stine, W.B., E.J. Carnegie., "Long Term Performance of 635 Tonne Pebble Bed In Continuous Operation", Solar Options Storage Workshop, March, 18-22, 1979, San Antonio, Texas, (through Trinity University).

5. Hannon, B., et. al., "Energy and Labor in the Construction Sector", Science 202, 837 (1978).

6. Hannon, B., et. al., "Energy Use for Building Construction Supplement", (Rept. COO-2791-4, U.S. Dept. of Energy, Washington D.C., October, 1977).

7. Dickinson, W., Cheremisinoff, Solar Energy Technology Handbook: Part B Chapter 7.9 (Marcel Dekker, Inc. N.Y., 1979).

PERFORMANCE OF A SOLAR HEATING SYSTEM FOR KILN DRYING LUMBER

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Abstract

This report contains a summary of the data obtained from a one-year test of a solar augmented lumber kiln in Canton, Mississippi. The test was conducted from 15 June 1978 to 12 April 1979 during which time the solar system operated 315 days and useful data were obtained for 180 days.

The test system consists of two 50,000 board feet capacity kilns (conventionally heated by gas/oil direct fire burners) solar heated by water/air heat exchangers in each kiln. The solar energy is collected by 2500 ft^2 of roof mounted Chamberlain double glazed, black chrome collector (augmented by 2300 ft^2 of anodized aluminum reflector), stored in a 5000 gal steel water tank, and delivered to the kilns as required. Some details of the system installation are shown in Figs. 1 through 3.

Operation and Control

Removing water from wood in a kiln is basically accomplished by maintaining a given schedule of dry bulb and wet bulb temperatures within the kiln which produces an environment dryer than the wood so that water leaves the wood and is absorbed into the air within the kiln. Generally, heat must be added to provide the energy of evaporation for the water, heat losses, etc., and low humidity air must be brought in at the same time that high humidity air is taken out of the kiln to remove the water vapor. The only complication that prevents this from being a very simple process is that wood shrinks as it drys, more in some directions than others. This differential shrinkage causes stresses that can warp, bend, split, etc., lumber as it dries. Preventing these problems by accurate control of the drying process is one of the main purposes of a modern kiln.

A typical hardwood kiln schedule is shown in Fig. 4. Note that the temperature required in the kiln varies from about 110 to 150 F. For all the species dried by LaCour the variations will be from 100 to 180 F. Wet and dry-bulb temperatures at any time are controlled by a pneumatic rate-proportional controller that senses the kiln temperature and the desired kiln temperature setting. The controller then opens or closes the fuel valve and/or air vents as required to drive the differences between actual and desired temperatures to zero.

To maximize the use of solar energy, it is desirable to supply solar heat whenever the storage temperature is higher than the kiln and the kiln needs heat. This should be done in such a manner that the fossil energy is used only to provide the energy not available from solar. For this facility, it was desirable not to add additional controls so the simple addition was made of a pressure switch which turns on the solar heat (water pump) whenever the existing controls call for heat and the kiln is heated. Water is then pumped through the heat exchangers shown in Fig. 3.

The solar collector is operated as a closed, drain-down system. The tank and collector plumbing are closed to the ambient and internal pressure is allowed to vary from -2 to +15 psig. The oxygen in the system becomes depleted rapidly and no further oxidization is possible until the tank temperature becomes so high that air (with steam) is blown off (which means that an equal amount of air will come back in the system as the temperature drops again. Draindown is accomplished by means of a solenoid controlled vent line from the tank ullage to the top of the collector manifold. This valve is normally open but closes when the collector pump comes on.

Instrumentation and Data System

The instrumentation utilized for this experiment was intended for monitoring system and subsystem performance. The data system was designed to collect data required for:

- Comparison of Test to Theory,
- Comparison of Solar Heated Kiln to Fossil Fueled Kiln and,
- "Troubleshooting" in the Event of a Problem.

The specific data that were recorded are:

- Solar flux at the collector tilt: Measurement of solar flux in the plane of the collector allows easy and accurate comparison of collector data and theory.
- Ambient temperature, wind velocity and direction: This was also used in comparison of collector test data and theory and to document the environment to which the system was subjected.
- Water flow rates and temperature differential across collectors and kiln heat exchangers: These data are necessary to determine the amount of solar energy collected and used by each kiln.
- Collector and heat exchanger inlet to outlet temperature difference: These measurements was used with the flow rates in determining the solar energy collected and used.
- Average storage, heat exchanger and collector inlet temperature: These data were for troubleshooting use primarily, but also to provide additional data on system operation.
- Kiln operating temperatures: These temperatures provide a means of determining the status of the kiln and progress of a drying cycle.
- Gas integrated flow rates: These data provide a simple means of determining the fossil fuel used by the kilns. The data monitored is integrated flow rather than rates to prevent any error being introduced by integration of a rate over a long period.
- Electrical energy used: A watt meter was used to determine the electrical energy used to collect and deliver the solar energy to the kiln.

Data aquisition and processing were accomplished through the use of a Digital Equipment Company (DEC) microprocessor based computer (PDP-11V03). All sensor outputs (variable resistance, voltage, or pulse rate proportional to measured parameter) were continuously supplied to signal conditioners (one per sensor) made by Action Instruments, Inc. These signal conditioners produces a 0 to 5 Vdc output that is proportional (usually linearly) to the value of the measured parameter. The 0 to 5 Vdc signal is continuously supplied to the computer by way of an analog-to-digital (A/D) converter which is controlled by the Data Acquisition/Reduction Program.

Collector Performance

The comparison of measured collector performance with predicted was somewhat complicated by the presence of the reflector. However, all indications are that the collector itself performed just as predicted by the manufacturer. This is illustrated by Fig. 5 which shows the total collector/reflector array efficiency for a day near the vernal equinox. In the morning and afternoon the reflector augmentation is predicted to be small and the measured efficiency agrees well with the predicted collector alone performance. The reflector augmentation is shown to be very noticeable during the middle of the day but was only half as much as expected.

A correlation was made for the total system performance for March 1979. These data are shown in Fig. 6 and the average daily efficiency as a function of $(T_{collector}-T_{ambient})$/total daily solar flux.

System Average Performance

By using the daily totals of solar energy collected, solar energy incident, and daily averages of ambient temperature and storage temperature, monthly averages and efficiencies were computed as given in Table 1. Also given in Table 1 are the peak collection days for each month and the corresponding daily efficiency.* Overall, the daily average energy collected was 1,170,000 Btu/day at an average efficiency of 35.1% and at an average collection temperature of 142 F. The average ambient temperature was 62F. Note that the best collection month was October 1978 which also had the best average daily efficiency of 44.2%. The peak collection rate of 2,830,000 Btu/day also occurred in October 1978.

Figure 7 is a graph of the monthly performance of the system and shows for each month the incident (available) solar energy per day, the collected solar energy per day, and the monthly average storage temperature and a ambient temperature.

The average electrical energy usage per day was 3.4 kWh. Using the fossil fuel equivalent, this represents 3% of the average daily solar energy collected.

Data on the fraction of the kiln heat load supplied by solar energy were sparse because of frequent problems with the auxiliary energy measurements (gas flow) but some usable data were obtained during July 1978 and September 1978. During the period 22-31 July, when the average collection rate was 1,780,000 Btu/day, the fraction was 21% for both kilns, 44.2% for kiln 1, and 28.5% for kiln 2. During the period 1 through 30 September, when the average collection rate was 1,260,000 Btu/day, which is a more representative case, the solar system supplied 15% of the heat used by both kilns, or 30% per kiln.

Comparison With Predicted Performance

The collector performance predicted in Phase I (Ref. 1) was compared with the measured performance as given in Table 1. The originally predicted

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[*] Daily efficiency, $\overline{\eta}_D$, is the ratio of the total collected energy (includes piping losses) to the toal solar energy received perpendicular to the collector.

average collection rate per day was 2.38 x 10^6 Btu/day, based on a predicted average daily solar energy availability of 1667 Btu/ft^2-day and a reflector aug-augmentation of 23%. The comparison to measured data is as follows:

	Predicted	Actual	Ratio
Collection, 10^6 Btu/Day	2.38	1.17	0.492
Average Daily Solar Energy, Btu/ft^2-day	1667	1261	0.756
Reflector Augmentation, %	23	Unknown	–

The actual solar energy collected was 49% of the predicted value. The reasons for this are:

1. The actual solar energy received was about three-fourths of that predicted.
2. The collector efficiency is lower at lower solar flux levels.
3. The total augmentation due to the reflectors was probably half of the predicted due to the accumulation of dirt on the reflector.
4. The kiln heat controller minimum heating rate was substantially higher than expected, causing less solar energy to be used than predicted resulting in higher storage and collector temperature.

Item 1, therefore, accounts for half of the reduction. Item 2 is the next largest effect, with Items 3 and 4 accounting for the remaining reduction to 49%.

Conclusions

The major conclusions reached during this experiment are:

1. About half as much solar energy was collected and supplied to the kiln as was expected. This was largely due to much lower solar flux than the average used for prediction, reduced reflector augmentation, and fuel control problems in the fossil burner as was discussed.
2. Little degradation in collector system performance was noted after 19 months of being subjected to a fairly severe industrial environment. The reflector augmentation has

apparently been reduced by about half during this time but the impact of that on total collector system performance is only about 10%.

3. The use of water heating collectors, water storage and water heat exchangers proved to be a good choice once the initial plumbing problems were solved. Storage is ample and the heat exchangers used in the kiln are capable of more rapid heat-up of lumber than was expected. Electrical energy is only 3% of the heat supplied.
4. The user is satisfied with the system from both a performance and maintenance view. The electric power consumed by the actual solar heating system is very small (though substantial electricity is used for data acquisition and heating/cooling the computer).
5. Obtaining good, complete, continuous data for a year is virtually impossible. The only hope to get an acceptable amount of data is to frequently check the system, frequently calibrate the sensors, and provide redundant instrumentation for the primary heat flow parameters.

Table 1

MONTHLY AVERAGE DATA

Month	$Q_{coll.}$ MBtu/Day	$Q_{sup.}$ MBtu/Day	n Days	Σ Flux Average Btu/ft^2-Day	$\bar{Q}_{Sol}$ MBtu/Day	$\bar{\eta}_{Mo}$	$Q_{c_{Max}}$ MBtu/Day	$(\bar{\eta}_{Day})_{Max}$	$\bar{T}_{Amb}$ F	$\bar{T}_{Stor}$ F
Jun 78	1.58	1.49	17	1593	3.98	39.7	1.98	44.3	81	160
Jul 78	1.81	1.77	14	1637	4.09	44.2	2.34	48.1	85	151
Aug 78	1.11	1.00	2	1830	4.58	24.2	1.60	35.9	86	176
Sep 78	1.26	1.18	23	1316	3.83	32.9	2.58	55.6	76	144
Oct 78	1.88	1.78	15	1855	4.64	40.5	2.83	53.4	66	160
Nov 78	0.88	0.78	28	1091	2.73	32.2	2.10	41.0	59	137
Dec 78	1.12	1.02	11	1390	3.48	32.2	1.80	47.1	47	126
Jan 79	0.42	0.33	18	631	1.58	26.6	2.45	45.9	40	119
Feb 79	0.56	0.48	25	769	1.92	29.2	2.16	42.2	48	125
Mar 79	1.57	1.46	25	1424	3.56	44.1	2.70	51.0	58	154
Apr 79	0.81	0.70	2	1576	3.94	20.6	1.09	32.0	68	168
Daily Avg.*	1.17	1.08				35.1			62	142

$Q_{c_{Max}}$ = Best Day of Collection

$(\eta_{Day})_{Max}$ = Efficiency on Day of Best Collection

*Weighted averages per days of each month used.

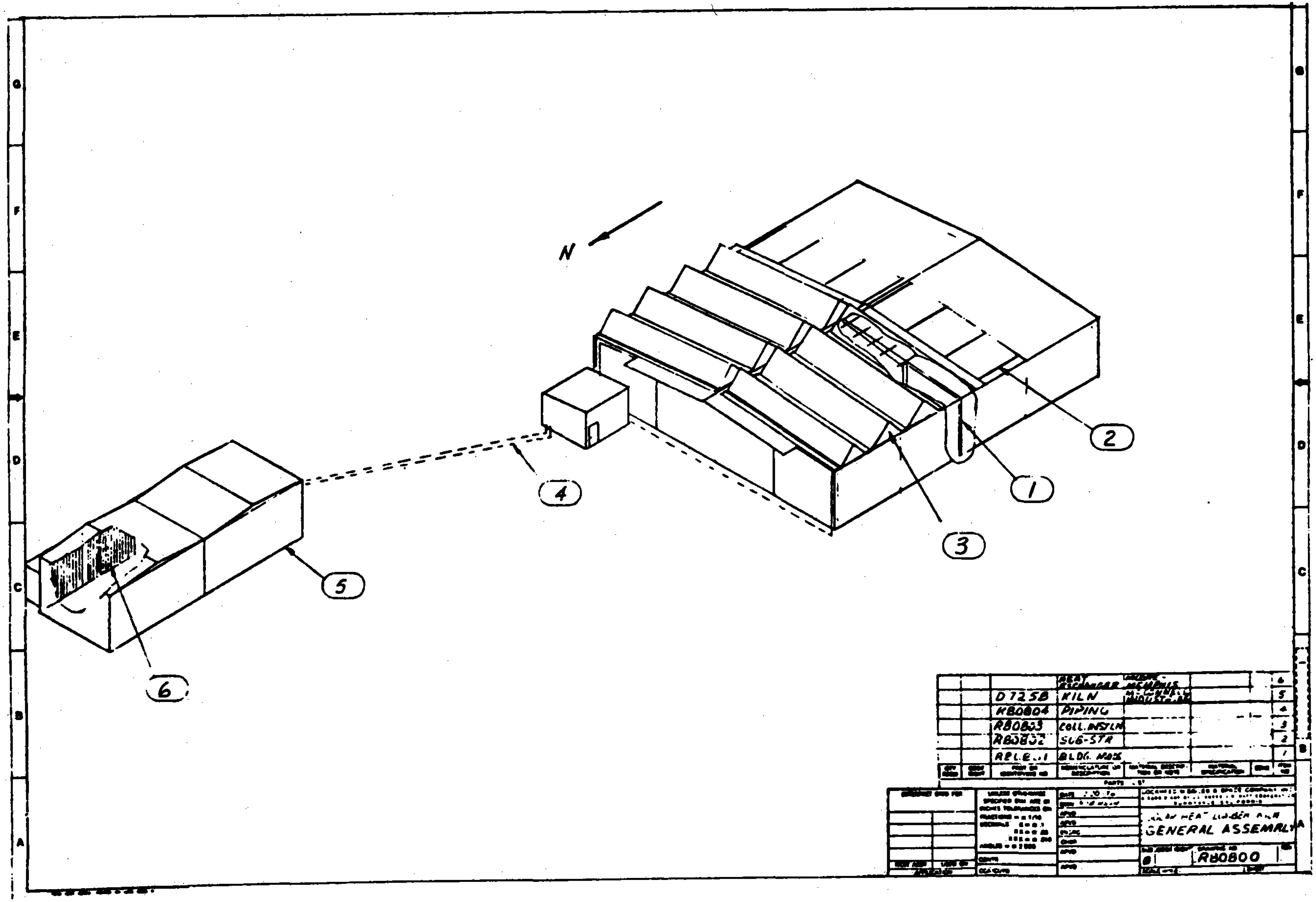


Fig. 1 - System Layout

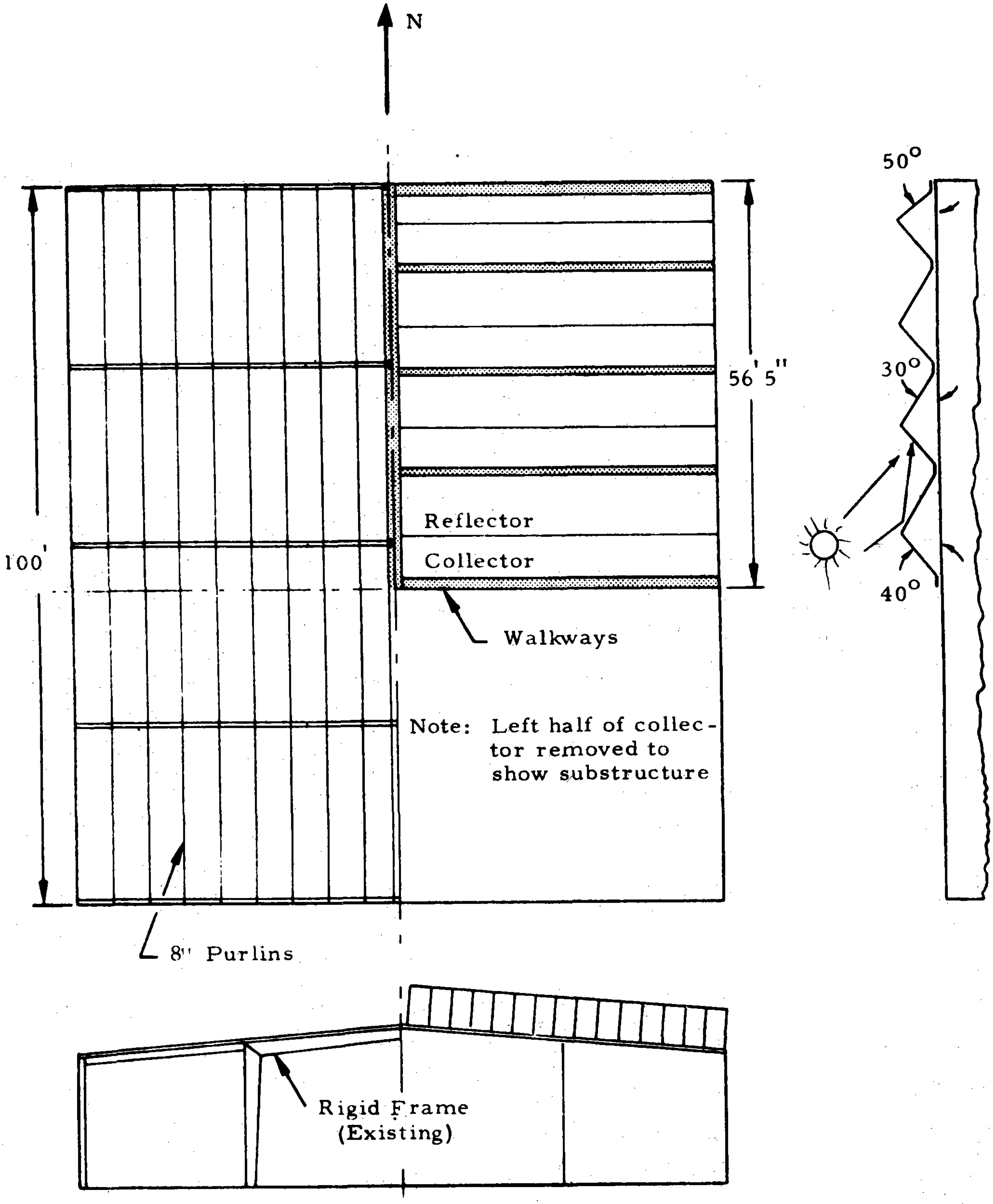


Fig. 2 - Layout of Collector System on Storage Building Roof

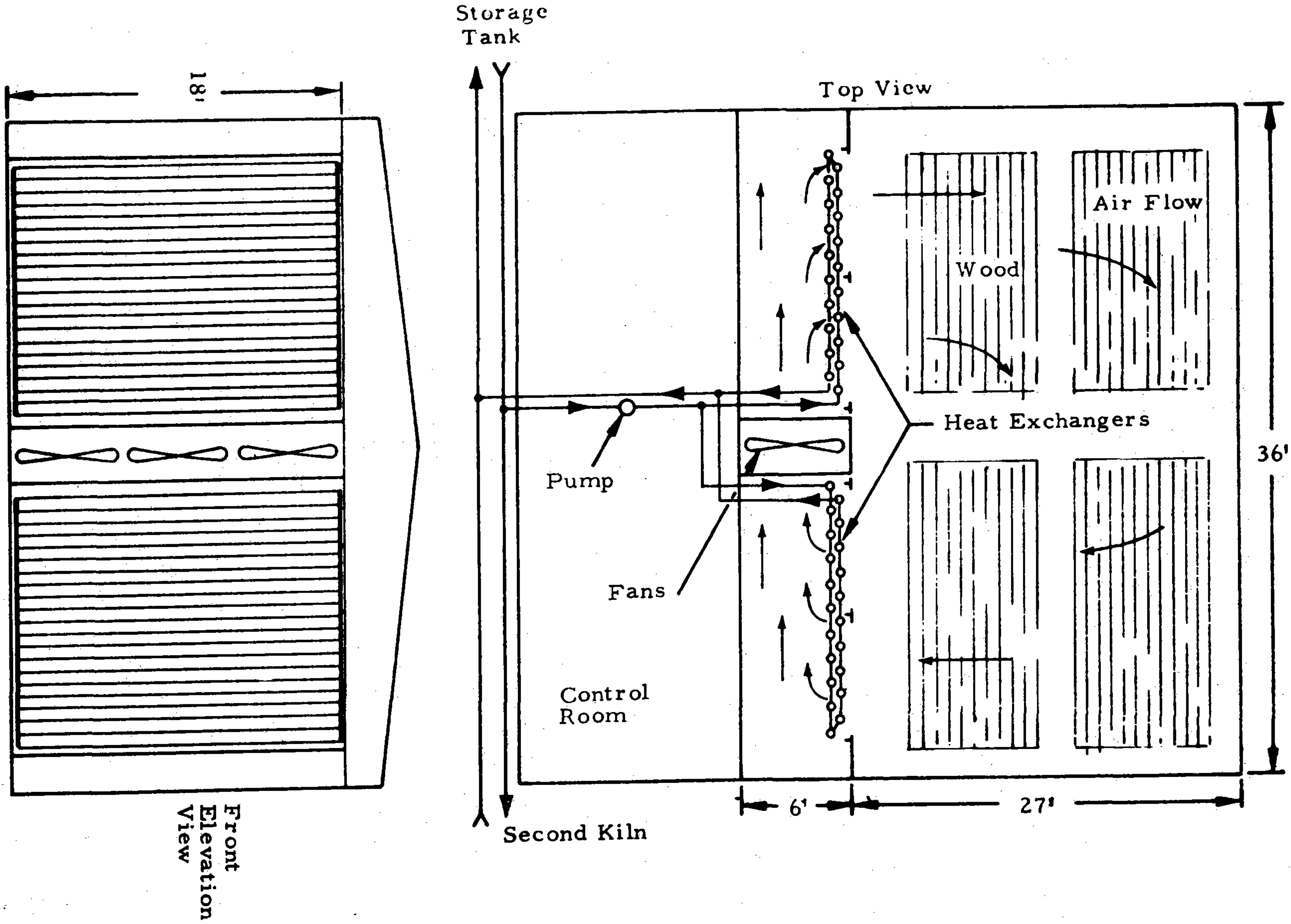


Fig. 3 - Schematic of Heat Exchanger Installation in Kiln

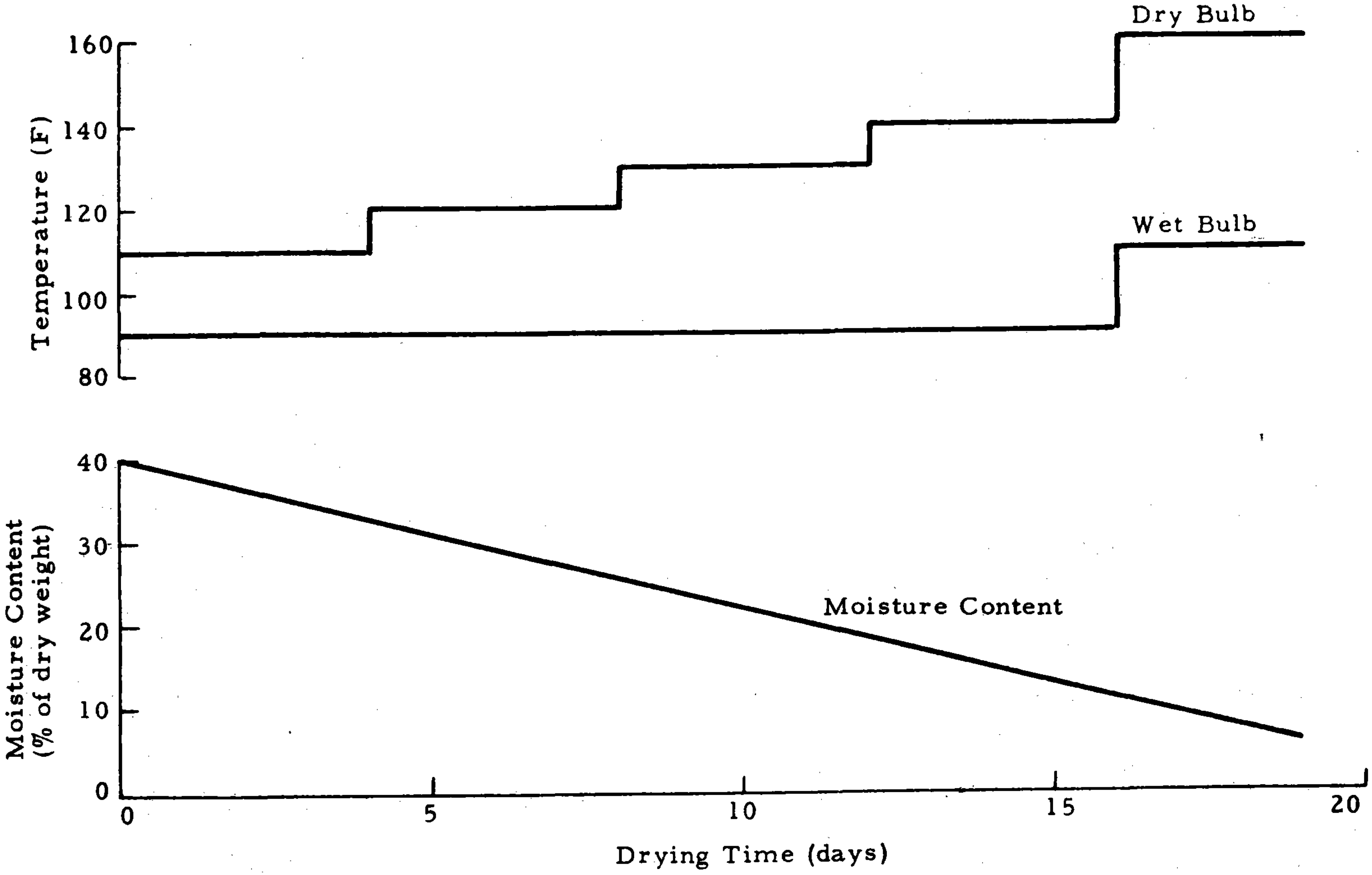
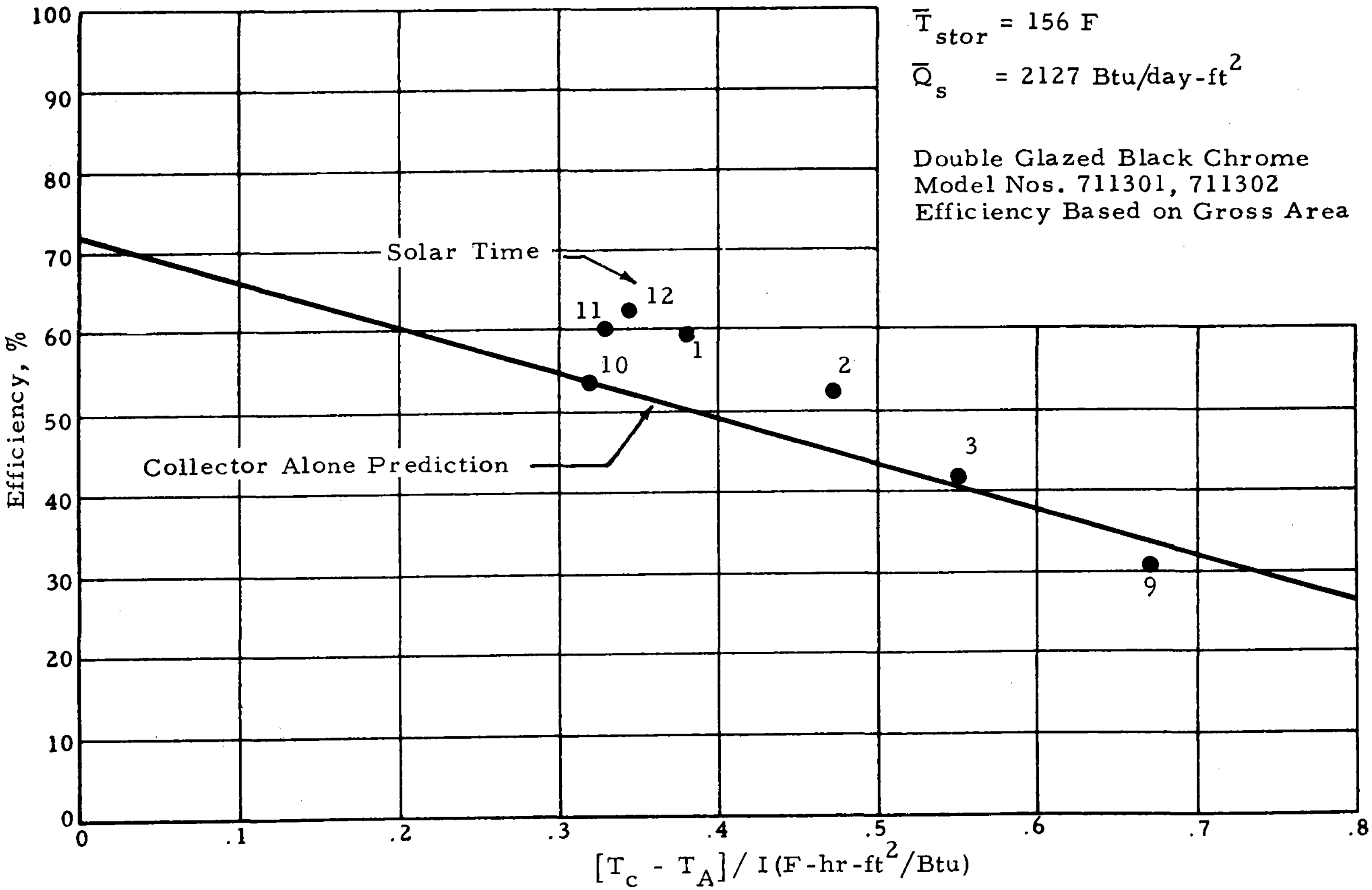


Fig. 4 - Drying Schedule for Tupelo Gum Furniture Squares



$\overline{T}_{stor} = 156$ F

$\overline{Q}_s = 2127$ Btu/day-ft^2

Double Glazed Black Chrome
Model Nos. 711301, 711302
Efficiency Based on Gross Area

Fig. 5 - Collector Efficiency, 24 March 1979, Hourly Average Data

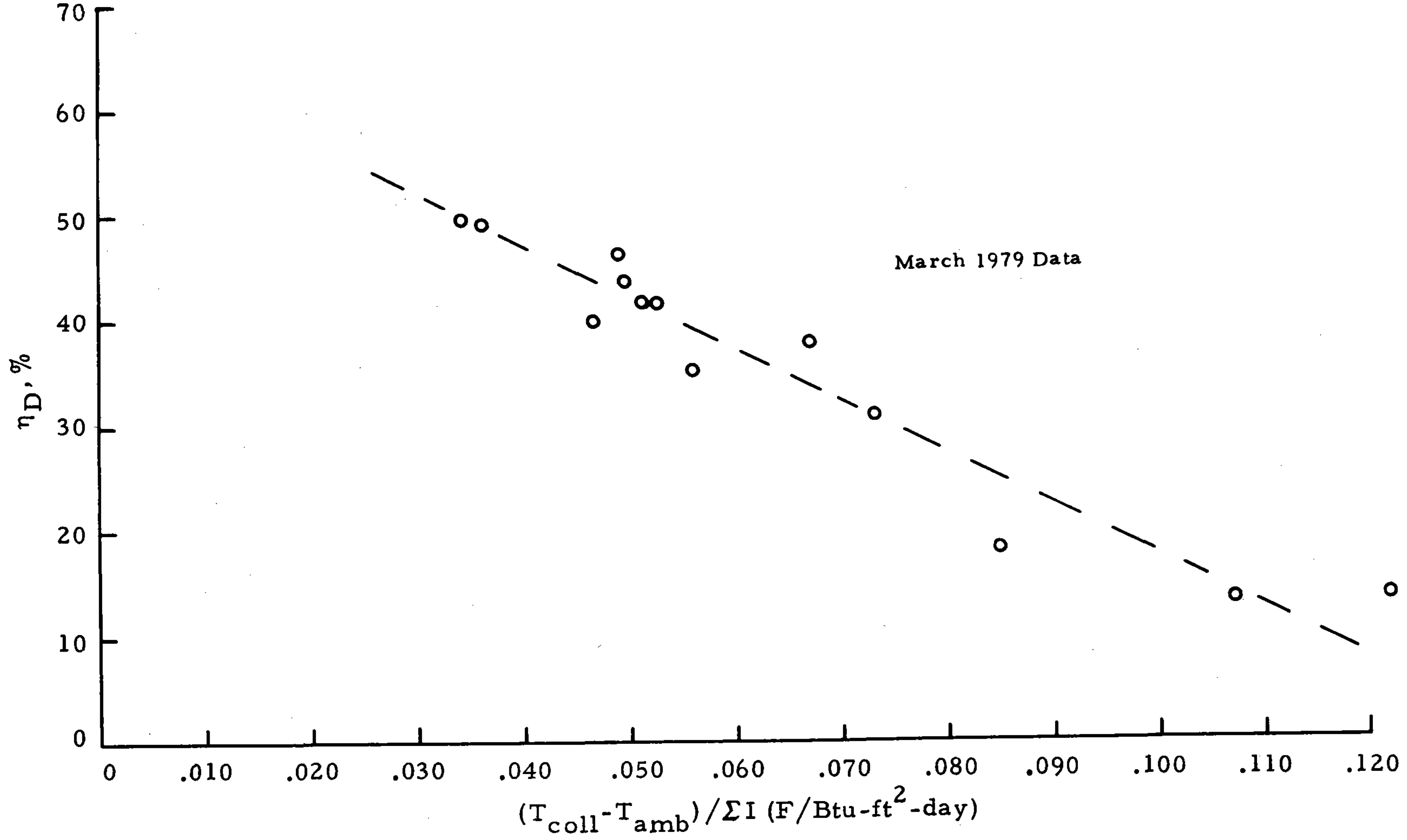


Fig. 6 - Daily Collector/Reflector Array Efficiency Correlation Plot

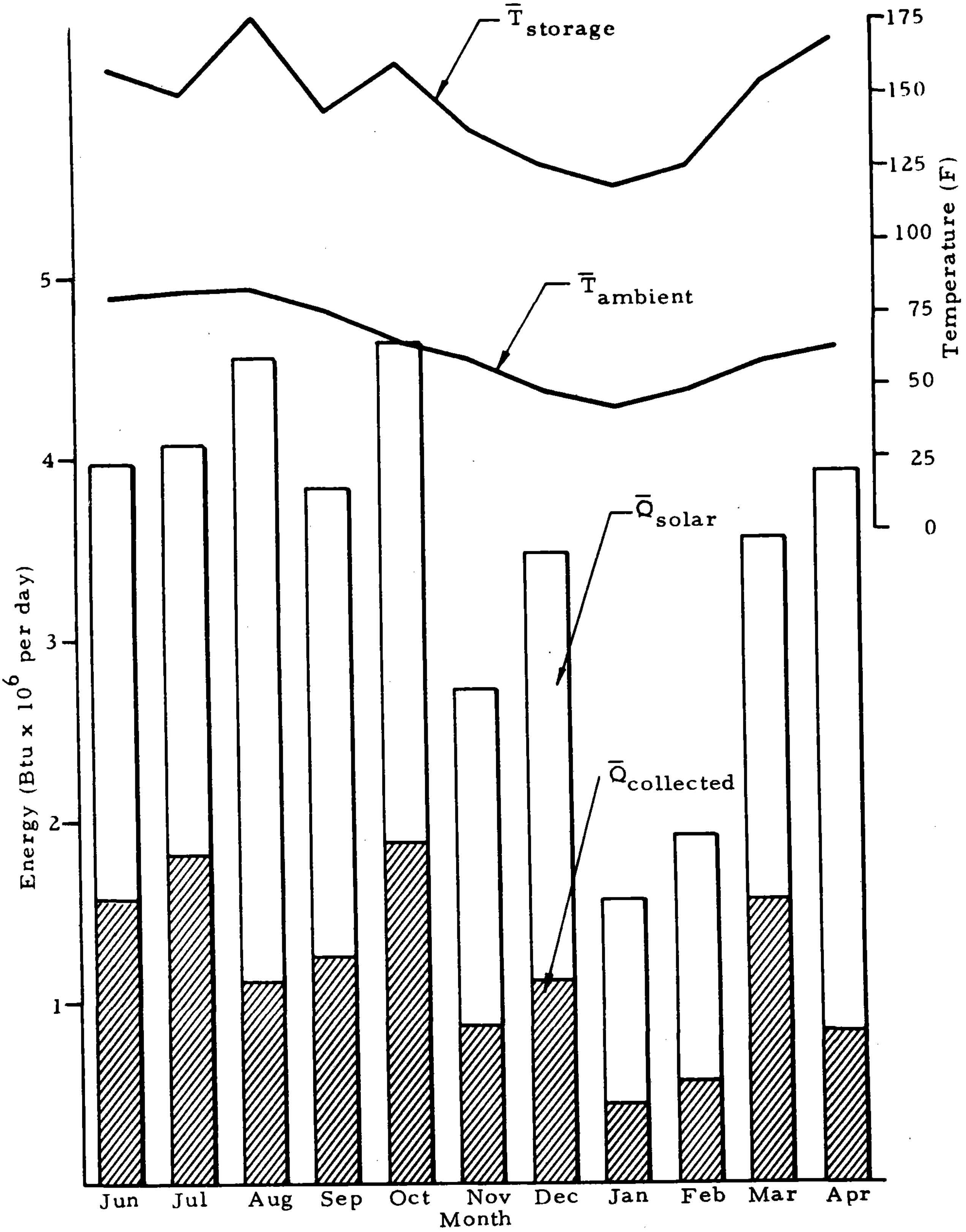


Fig. 7 - System Performance – Monthly Averages

SOLAR AUGMENTED SOYBEAN DRYING

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ABSTRACT

The objective of this overall project was to provide analysis, design, fabrication, and demonstration of a solar energy system for process drying of soybeans. The system consists of an array of 672 air collectors that preheat the inlet air to existing continuous-flow dryers at the Gold Kist Soy facility at Decatur, Alabama. This experimental system, sponsored by the U.S. Department of Energy (DOE), has been operational since June 1, 1978. Because of soybean process equipment maintenance, a system utilization of only 54.7% was achieved. The 1,215-m^2 (13,104-ft^2) system delivered 0.867 TJ (822.5×10^6 Btu) or 1.3% of the energy requirement for one dryer in the first year of operation. This paper, oriented to Phase III, Performance Evaluation, will describe the facility and the first year of operation and present performance, operational, and life-cycle cost analyses.

CONTRACT DATA

Contract No.: DE-AC05-76CS35122
User Industry: Gold Kist, Inc., Decatur, Alabama
Contract Period and Funding:
Phase I, Design; 26 May '76 - 25 Jan '77; $286,764
Phase II, Construction; 12 Jul '77 - 31 May '78; $747,912
Phase III, Performance Evaluation; 11 Sep '78 - 31 Oct '79; $126,188

INTRODUCTION

To demonstrate the applicability of solar energy to industrial uses, DOE initiated this three-phase program to design, construct, and evaluate a solar system for the industrial drying process and to provide an assessment of the economic and resource benefits of such a system. Phase I was a 9-month project to design and analyze the system; in Phase II, an 11-month period was devoted to construction and checkout of the system; and the recently completed Phase III provided data sufficient for a thorough performance and economic evaluation of the first year of operation.

The results of Phases I and II are now published and in the literature. Detailed results of Phase III are contained in the final report, dated October 31, for this phase. This paper presents a brief system description and summarizes the results of the performance evaluation phase. All three phases were performed under the DOE/Industrial Process Heat (IPH) program by Teledyne Brown Engineering as the prime contractor.

SYSTEM DESCRIPTION

The Gold Kist, Inc., extraction plant at Decatur, Alabama, was chosen as the demonstration site. This plant employs three large continuous-flow dryers manufactured by Ferrell-Ross. Each dryer is capable of drying 3,000 bu per hour. They are fueled by either No. 5 fuel oil or natural gas. The fuel flow rate is adjusted manually to maintain proper bean moisture content at the output.

The solar system provides preheated air to any or all of the dryers. Solar heated air is ducted and exhausted in the immediate vicinity of the dryer air intakes and is entrained therein, reducing the quantity of fuel required to maintain a given dryer bed temperature. The solar system consists of the following major subsystems: collectors, structure, and energy transport and controls subsystems. It also includes a data acquisition system to support the experimental nature of the program. Since the soybean dryers are capable of instantaneously using the entire solar system capacity, no thermal energy storage system was provided. The system is shown schematically in Figure 1.

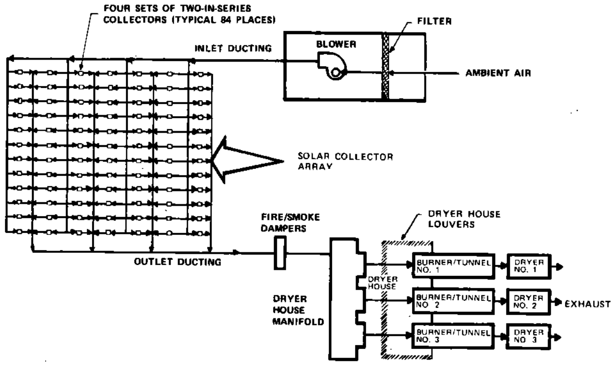


Figure 1. Schematic of Solar Drying System

The collector subsystem consists of 672 Solaron single-glazed air collectors (13,104 ft^2). A cost/performance tradeoff study conducted in Phase I resulted in a 15-deg tilt for the array. For asthetics, it was oriented 24 deg east of south to align with a row of large silos.

The energy transport subsystem delivers 27,000 ft^3/min of ambient air through the collectors to the dryers. This subsystem consists of conventional air handling equipment, commercial ducting, and fire dampers. A blower located on the upstream side of the collectors prevents the ingestion of contaminants at leakage points. Solar heated air from the collectors is delivered to the dryer house through a 4- by 4-ft galvanized metal duct. All hot air ducting has 2 in. of fiberglass insulation coated with a weatherproof mastic. The transport ducting conforms to SMACNA and ASHRAE criteria for industrial ducting.

The transport system supply duct terminates with three inlets (with dampers) to the dryer house. Each inlet is located directly in front of a dryer air inlet. This type interface provides minimal impact on conventional operation of the dryers.

A standard Penn Control ΔT type controller is used to control the system. When the collector temperature exceeds ambient by 15°F, the system trips on. Trip-off occurs when the collector temperature is within 7°F of ambient. The solar system also has an electrical interlock with the dryers that makes the control system completely independent of operational personnel.

SYSTEM OPERATIONS

System operations formally began on June 1, 1978, and lasted through August 31, 1979. During this period, the solar system operated for 1,752 hr without a major malfunction. Regular processing operations were uninterrupted by the solar system. The only requirement of plant personnel was routine cleaning of the glazings and repair of one small duct. The total maintenance cost for five quarters of operation was $1,564.

Glazing contamination was a significant factor in this program. The local environment at Gold Kist contains soybean oil, chaff, and dust, which collected on the surface of the collectors. Analysis of samples by The University of Alabama in Huntsville (UAH) revealed that the oil in the contaminate polymerizes in the presence of ozone and ultraviolet, creating a varnish-like substance. Using the high-pressure cleaning system with detergent injection and long-handle brushes, three men typically cleaned the entire array in 6 to 8 hr, depending on the degree of contamination.

DATA ACQUISITION

The data acquisition system consisted of eight RTD-type temperature sensors, a pyronometer, a hot wire anemometer, a watt transducer, a relative humidity sensor, and a Fluke Model 2240A data logger. The printed data were keypunched for processing on TBE's Varian V-73 computer.

Early in the program, performance results indicated a negative loss (gain) in the main supply duct. Using a thermocouple, it was discovered that the temperature across the section of the duct varied in a random manner as much as 2.5°F at each end of the duct. It was concluded that a set of multiple thermocouple devices would be required to accurately measure the duct loss. The duct loss was then calculated to be 2.5% of the energy collected and this value was used throughout the program.

Quarterly calibration of the RTDs revealed little drift, and only minor adjustments were necessary. Only the first anemometer calibration required any significant adjustment. The pyronometer readings were compared with those of an identical instrument at UAH, with less than 1.7% difference in any set of readings. The Fluke data logger failed for a brief period in mid-winter. The instrumentation shack heater was left off and the temperature exceeded operational limits for the equipment. The repair required 8 days, but due to cloud cover and plant maintenance shutdowns, only 8 hr of data were missed. Generally, the data acquisition system used was extremely reliable and accurate. It is estimated that less than 2% of the available data were lost due to malfunction of the data system.

OPERATIONAL ANALYSIS

Although the solar system was operational for 15 months, all data presented herein are for the final 12 months of operation. This period was chosen due to slight instrumentation errors in flow measurement during the first 3 months.

A major problem associated with the operational phase was low system utilization. Gold Kist performed their routine plant maintenance during the day shift. Many times the dryers were directly or indirectly affected and had to be shut down. This, of course, caused automatic shutdown of the solar system. The overall system utilization was 54.7%. This parameter accounts for solar energy available (with cloud cover) and the hours of system run time.

The solar system displaced 822.5 × 10^6 Btu fuel equivalent during the first year. As shown in Figure 2, this would be 1,430 × 10^6 Btu assuming 95% system utilization. Monthly average collector efficiency ranged from 28.3% in September to 23.4% in February. The annual average efficiency was 26.2%. Attributable to this lower-than-expected efficiency are such factors as glazing contamination and high air velocities along the rear surface of the collector array. As evidenced by the data before and after cleaning, the contamination accounted for 6% to 10% loss in efficiency, depending on the degree of contamination.

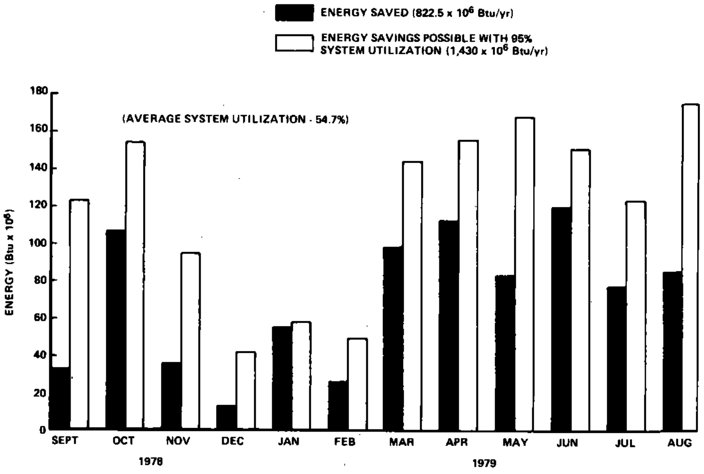


Figure 2. Monthly Energy Savings

Typical temperature lifts ranged from 40°F to 60°F. Figure 3 presents profiles of collector outlet temperature and ambient temperature for an August and a January day.

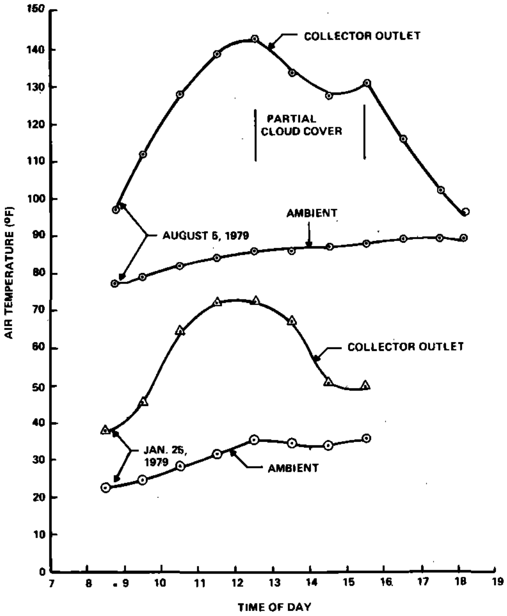


Figure 3. Collector Outlet and Ambient Temperature Profiles

CLEANING SYSTEM CONCEPT DESIGN

A prototype cleaning system, consisting of an oscillating, direct-impingement type spray system, as shown in Figure 4, was installed. This system, covering 32 panels (624 ft), proved very effective in collector cleaning. A car-wash type detergent was injected into the main water line. System cost studies indicated an installed cost of \$2.35/ft^2 for a fully automated system.

ECONOMIC ANALYSIS

The economic and operating ground rules provided by DOE prescribed the following: $i = 10\%$, $e = 0$, and $N = 20$ years. The economic analysis conducted assumed a reduced structural subsystem cost and a system utilization of 95%. Using a cost of \$405,615 (\$30.95/ft^2) and the real annual ownership, operation, and maintenance cost totaling \$3,257, the life cycle cost per million Btu of solar derived energy is \$48.10.

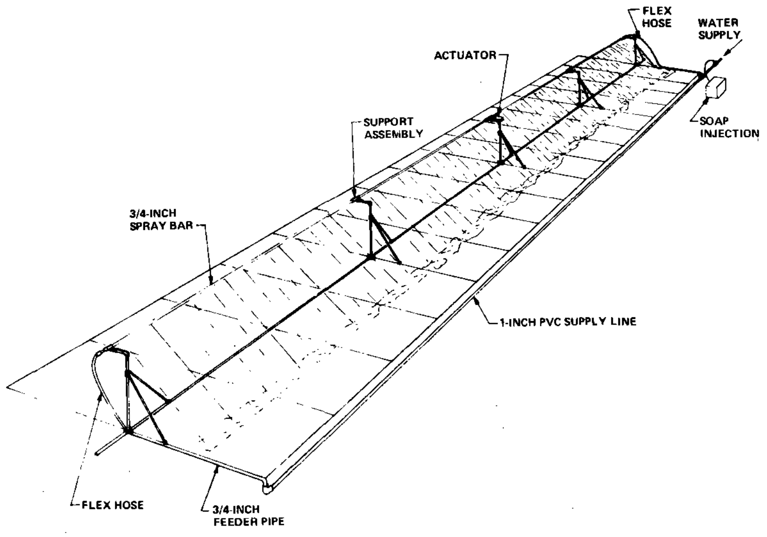
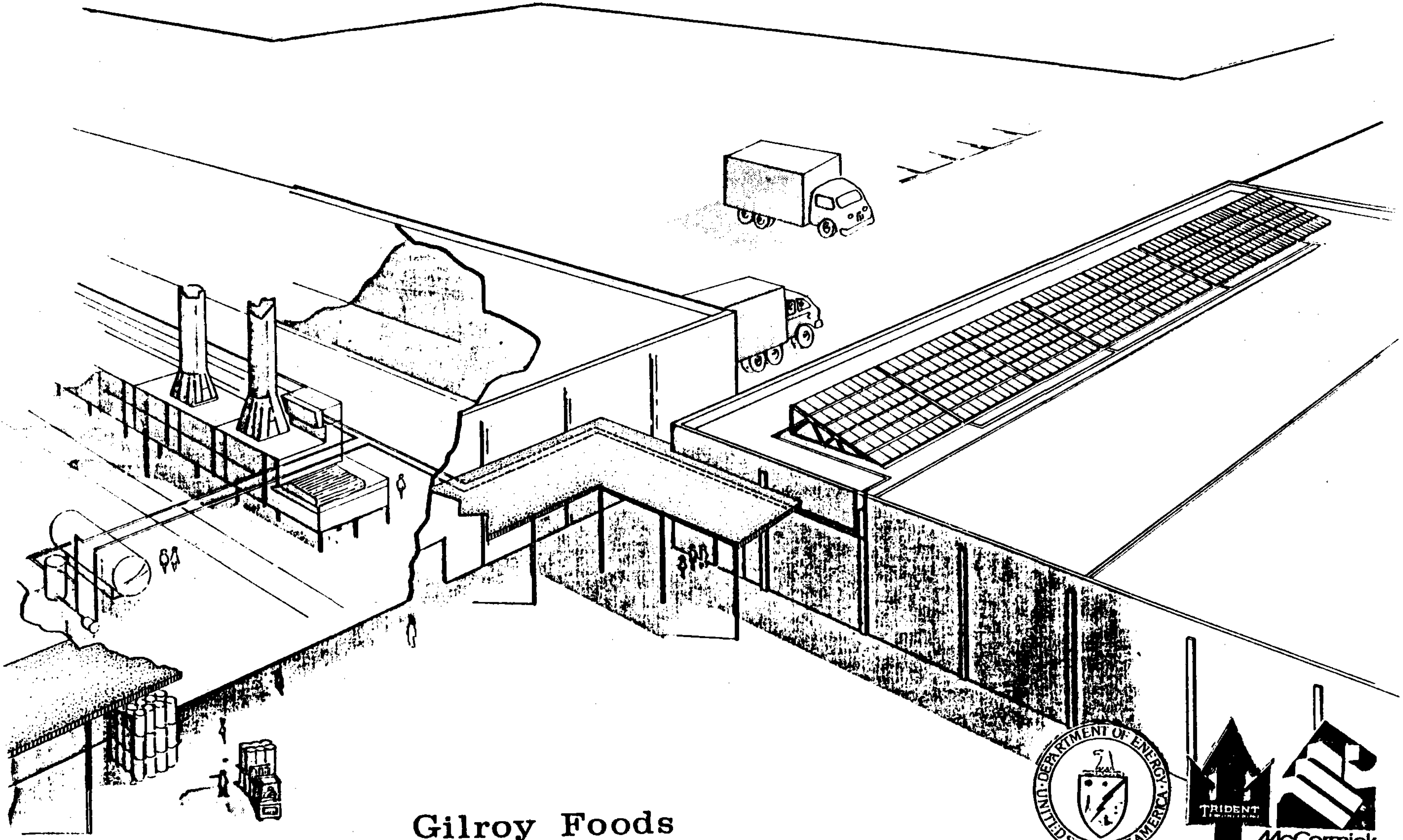


Figure 4. Prototype Cleaning Systems



Gilroy Foods
Solar Project

APPLICATION OF SOLAR ENERGY TO CONTINUOUS BELT DEHYDRATION

P. D. Sierer, Jr.
Trident Engineering Associates, Inc., Annapolis, Md.
D. Powell
Gilroy Foods, Inc., Gilroy, Ca.

BACKGROUND

Contract No. DE-AC05-76CS-35119 was awarded by ERDA, now Department of Energy, to Trident Engineering Associates on May 25, 1976 for development of a preliminary design of a solar energy system for installation at the Gilroy Foods dehydration plant in Gilroy, California. By modification no. A005, dated May 4, 1978, Trident was authorized to proceed with the 13-month program for construction and check-out of the system. The final phase of the project, Phase III - Project Operation and Evaluation, commenced in July 1979. Project funding by phase is as follows:

° Phase I	- Project Preliminary Design........	$225,970.00
° Phase II	- Construction and Start-Up.........	$617,871.00
° Phase III	- Operation and Evaluation..........	$177,721.00

Project Location and Industrial Partner

The work site is located at the dehydration plant of Gilroy Foods, Inc., at Gilroy, California, a wholly-owned subsidiary of McCormick & Company. Gilroy Foods, Inc. is a major producer of dehydrated onion and garlic products. The solar system is intended to provide solar-generated heat to the drying process to supplement heat produced by conventional gas-fired burners.

Size and General Scope

The design consists of a single 552.7 m² (5959 ft²) collector field composed of evacuated tube collectors which use water as the heat transfer fluid. The collector modules are mounted on a warehouse roof by means of a prefabricated support structure. The warehouse roof at the Gilroy plant was selected as well-suited for the location of a collector field since it is relatively free from onion dust, is relatively flat and free from protruding obstructions, has considerable additional area for expansion of the collector field, and the structural frame of the building has adequate strength for the support of the solar collectors and their support structure. The final system design provided for a collector array of General Electric TC-100 evacuated tube solar collectors.

GILROY SOLAR PROJECT SYSTEM DESCRIPTION

General

The Gilroy Solar Project fluid system is designed to heat water up to 90°C (194°F) in evacuated tube solar collectors, transport the heated water through an insulated piping system to a heat exchanger mounted in the incoming air stream to the first stage of a large, continuous-belt onion and garlic dehydrator. The hot water preheats the incoming air, reducing the requirement for natural gas which formerly was the only source of heat for preheating air entering the dehydrator.

The onion and garlic dehydration process is seasonal in nature, and operates only during the harvesting season from May through October. Accordingly, the array is mounted at an angle of 22° to the horizontal to optimize sunlight energy collection during this period of time. During periods when the dehydrator is not operational, an alternate heat sink is provided by the plant boiler condensate collection tank. Solar system fluid flow is automatically diverted to the alternate heat sink whenever the dryer, the primary heat sink, is unable to accept thermal energy from the solar collector. Since the plant boiler is in operation 12 months of the year, this system capability ensures not only emergency heat absorption, but also full utilization of the solar energy collected throughout the year and under abnormal production conditions. A system flow schematic illustrating alternate heat sinks is shown in Figure 1. The characteristics of the system, including design and operating parameters, are tabulated in Table I.

TABLE 1

GILROY FOODS SOLAR ENERGY PROJECT
SYSTEM DESCRIPTION

System Purpose	Process Heat, for onion/garlic dehydration
Solar Collector	General Electric TC-100 Evacuated Tube Solar Collector Design Characteristics Normal Size: 4'-0" x 4'-0" Number of Vacuum Tubes: 8 Weight Filled: 59 Lbs. Frame: 18 Ga. Aluminized Steel Reflector: Polished Aluminum Fluid Lines: 1/4" Copper Tube Module Area: Total Frame 1.62 m^2 (17.4 ft^2)-[active*] 1.38 m^2 (14.8 ft^2) Flow Rate: 0.22 GPM Pressure Drop-Design: 7.0 psi @ 82°C (180°F) Operating Temperature: 38°C (100°F) to 149°C (300°F)
Number of Collectors	402 Modules
Slope Angle of Collectors	22°
Area of Collectors	553 m^2 (5950 ft^2) [active*]
Heat Transport Fluid	Demineralized Water
System Flow Rate	88 Gallons per Minute
System Operating Pressure	65 psig pump discharge - 30 psig collector inlet
System Operating Temperature	90°C (194°F)
Maximum Heat Production Rate	1.16 x 10^9 J/hr (1.1 MBtu/hr)
Total Annual Heat Production Rate	2.47 x 10^{12} J/hr (2340 million Btu/yr)
Piping System	2-1/2" Diameter Copper Pipe
System Insulation	1-1/2" Fiberglass
System Control	Automatic Data Acquisition and Systems Control with Remote Command Capability
Module Cleaning	Automatic Washdown System

* *Heat producing area*

System Operation

The system has several modes of operation which are automatically selected depending upon conditions sensed by the system data acquisition and control system.

Standby Mode

The standby mode of system operation is in effect under normal operating conditions when incident sunlight on the array is less than 25 BTU/hr·ft² and system fluid temperatures are less than 40°C. In this condition, system recirculating pumps are off, the system is in a closed loop configuration, and system pressure is automatically maintained between 10 and 30 psig at the base of the collector array.

Normal Operating Mode

The normal operating mode is initiated whenever the total solar insolation incident on the array exceeds 30 BTU/hr·ft². The system pump circulates water in a closed loop consisting of the solar collector array, the air-water heat exchanger, and the pump. In this mode of operation, the system pressure is automatically maintained between 25 and 30 psig at the base of the collector array.

Alternate Heat Sink Mode

This mode of operation is automatically selected whenever the outlet temperature of the solar collector array exceeds 90°C (194°F). Such a condition indicates that the heat exchanger is either bypassed, or air flow through the heat exchanger is inadequate to absorb the heat generated in the solar collector array. When collector array outlet temperature exceeds 90°C (194°F), the air-operated valves change position and divert flow through the condensate tank, rejecting heat to the boiler condensate water reducing natural gas requirements of the plant boiler. In this mode, the system acts as an open recirculating system, and system pressure is controlled by system flow characteristics. Pressure at the base of the collector array is typically 23 psig in this mode of operation.

Freeze Protection Mode

In winter, there are occasional periods at night when ambient temperatures in the vicinity of Gilroy drop below freezing. When a temperature of 36°F (2°C) is sensed in the solar array fluid, the system is automatically started in the alternate heat sink mode. Recirculation is continued until a temperature of 40°F (4°C) is sensed, at which time the system reverts to the standby mode.

Data Acquisition and Control

System Design

The data acquisition and control system for the Gilroy Solar Project was designed around a micro-processor unit which has the capability to:

- Scan multiple channels;
- Store data;
- Average stored data;
- Compare measured values of input data against a preset value and activate switching circuits when preset values are exceeded;
- Permit remote command of all system functions;
- Read out stored data.

The data acquisition and control system installed at the Gilroy Foods Solar Project is shown schematically in Figure 2.

Remote Command Capability

System monitoring for proper operation is the responsibility of Trident Engineering. Accordingly, a remote command and control system has been established at the Trident offices to permit remote data collection, system operation, and system diagnostics.

Dust Control

A test to determine the nature and extent of the problem caused by dust settling on the collectors, particularly high sugar content onion skins, was conducted during the early months of Phase II. The test indicated that contamination by onion skin dust was negligible, and other agricultural dust which collected was easily removed by water washing. However, since, during the onion drying season, rain is unusual, and since dust can result in a significant degradation of performance (10-15%), an automatic irrigation-style sprinkler system is being installed to control dust accumulation.

INITIAL OPERATIONAL RESULTS

The Gilroy solar system began initial operations for heat production on July 1, 1979. Heat delivery to the process began smoothly and with no disruption to the dehydration process. Typical performance characteristics recorded during initial operation indicate the system is performing well. Data from an initial period of operation yielded the following performance results:

Hours operational for the day	12 hours
Heat delivered to the process	4.714 MBTU/day
Net system energy production	4.604 MBTU/day
Daily gross efficiency	34.12%
Daily net efficiency	33.33%

The only parasitic loss considered for the system in calculating net energy production and efficiency is pumping power. Other inputs, such as power for instrumentation, was considered to be negligible. The maximum rate of heat delivery to the process has been approximately 1 MBTU/hr.

Evaluation of Initial Operation

The results of initial operation very closely approach design estimates of performance. Fluid system performance, with respect to pumping power flow rate, and pressure distribution were exceptionally close to predicted values. Actual flow rate, for example, was within 1 gpm of the design flow rate of 88 gpm.

Initial results of heat production appear to be 10-20% below predicted values. This is attributed to the dust accumulation on the collectors. The reflectors had been exposed to dust contamination for several months before system operation commenced.

PROJECT PHASE III WORK

The system is now operational, providing heat energy on a daily basis to dryer 5 for the dehydration of onions. Work which is still required and which will be pursued during Phase III, Operational Evaluation, includes the following:

- Optimize system set points, such as pressure control band, pump start-up and shut-down, etc., to minimize parasitic losses;
- Install a water washdown system to improve collector efficiency;
- Evaluate the improvement in performance the washdown of the collectors provides;
- Develop operating and maintenance procedures.

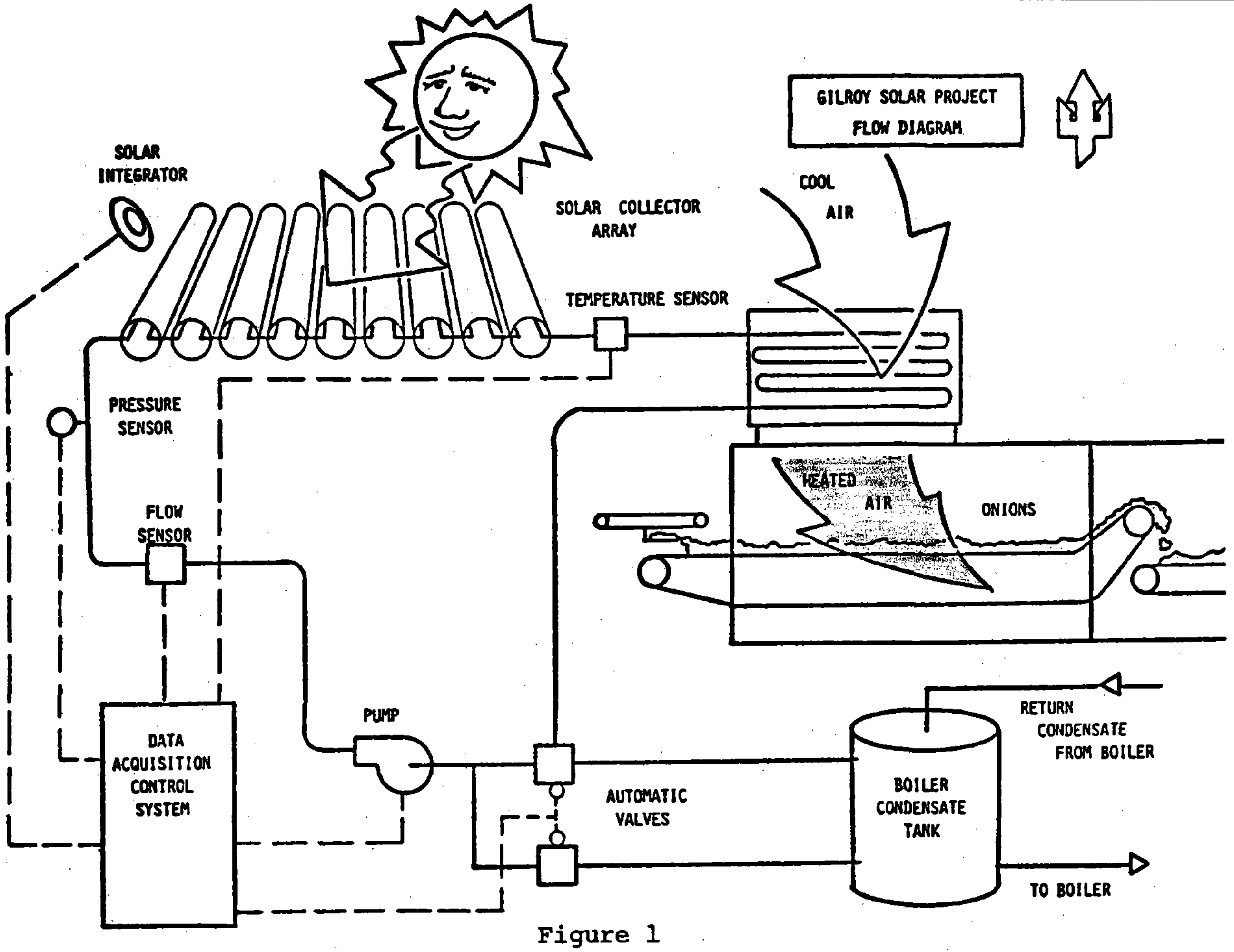
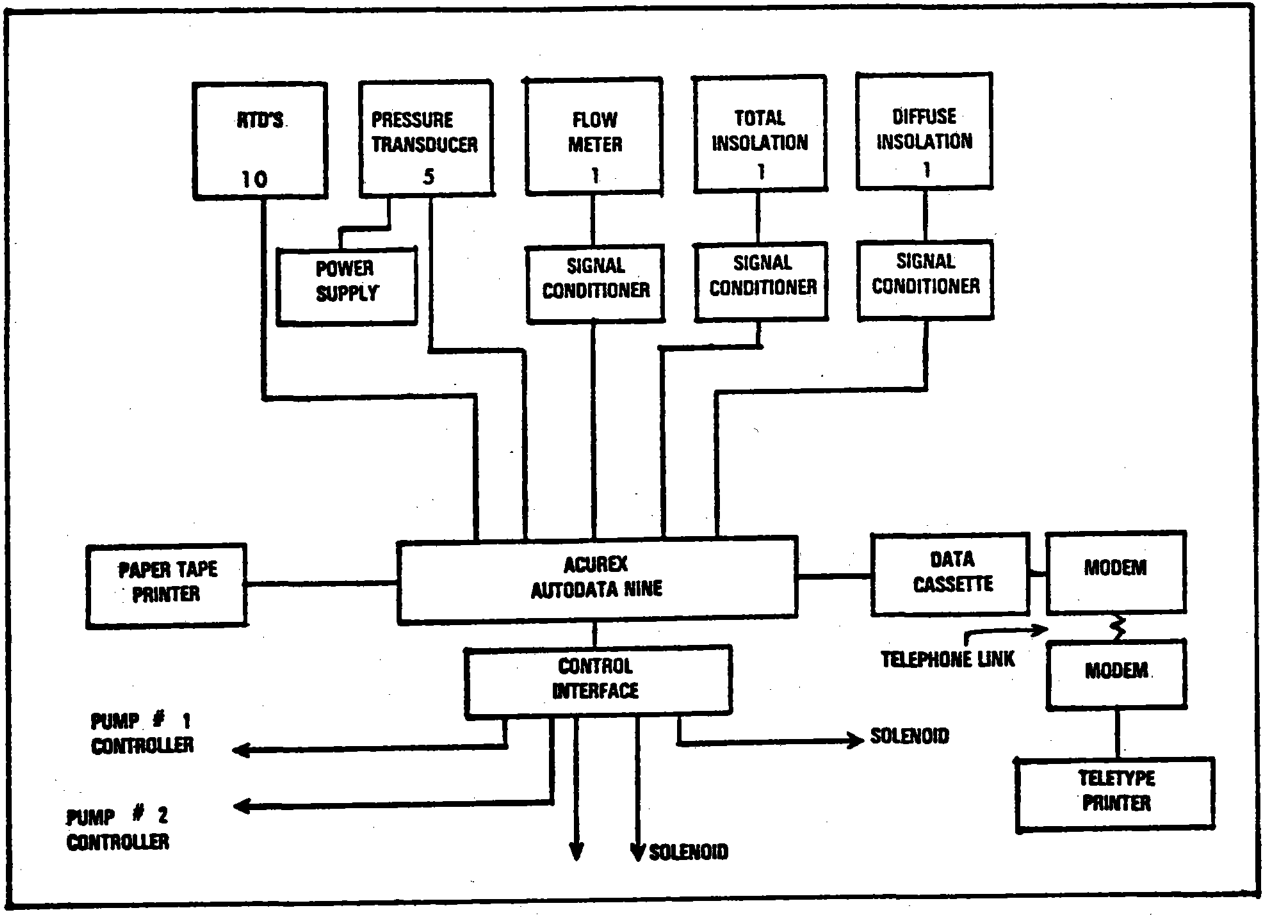


Figure 1



DATA ACQUISITION AND CONTROL SYSTEM

Figure 2

Low Temperature Steam

TEXTILE DRYING AT WESTPOINT PEPPERELL USING SOLAR PROCESS STEAM

Contract No. E(40-1)-5124

P. D. Mitchell
Energy Resources Center
Honeywell, Inc.
Minneapolis, Minnesota

ABSTRACT

A solar process steam system for providing process heat to a textile drying process has been designed and installed at the WestPoint Pepperell MARTEX towel mill in Fairfax, Alabama. The system consists of five major subsystems: the collector field, the high temperature water loop, the steam generator, the steam loop, and the process. The collector field consists of 24 parabolic trough, single axis tracking, concentrating collectors. The high temperature water loop is the piping which transports the solar energy from the collector field to the steam generator. The steam generator is a commercially available unfired package boiler. The steam loop is the piping which transports the solar steam to the process, and returns the condensate back to the boiler as feedwater. The process being solarized is a line of "slashers" which use steam heated drying cans to dry the textiles.

The system is designed to generate 380°F water at the collector outlet to feed the steam generator. The steam generator will provide 76 psi (320°F) steam to the process. Under peak insolation conditions, the system is expected to deliver 1,000 lbs. of steam to the process. Computer simulations using local weather data indicate that the system will deliver about 10^9 Btu's to the process annually.

PROCESS

The slashing process is common to textile griege mills since 50% of all woven yarn (the warp) must pass through the slasher in preparation for weaving. The slasher applies a liquid cornstarch to the yarn for protection and lubrication, then dries the yarn by direct contact with hot cylindrical can dryers. The slasher steam manifold is maintained at 70 psi by a pressure regulator off of the main high pressure steam line. The drying cans themselves are set at some pressure (less than 60 psi) to maintain a proper drying rate. The slashers operate 24 hrs. a day, 6 days a week, except for stoppage to unload and load.

SYSTEM

The solar energy system designed to provide process heat for textile drying consists of five major subsystems:

- the collector field
- the high temperature water (HTW) pipe loop
- the steam generator
- the steam pipe loop
- the process

Figure 1 is a simplified system schematic showing these five major subsystems. The collector field contains 24 concentrating collectors which utilize parabolic trough shaped mirrors and tubular receivers, and follow the sun by means of single axis tracking. The HTW loop transports the collected energy to the steam generator in the form of 380°F water. The steam generator is an unfired package boiler. The steam pipe loop transports the solar generated steam to the textile process. The process consists of cylindrical can dryers used in drying textiles in a slasher line.

Collector Field

The collector field consists of 24 concentrating collectors arranged on the weave room roof. The field provides 7500 square feet of mirror. Spacing between collector axis is 10' 8" which eliminates shadowing from adjacent collectors unless the sun is below 22° elevation. The collector field is aligned along the building coordinates.

The collector is a half-parabola mirror concentrator focusing solar energy on an insulated tube receiver. The mirror is constructed of aluminum honeycomb with a reflective surface applied. Four 20 ft. x 4.3 ft. mirrors per collector result in 313 square feet of active mirror per collector unit. The collector rotates through 270° to allow stowing in a mirror downward position.

A motor/gearbox drives the mirror assembly via a torque tube under the control of a sun tracker. The pivot axis is at the middle of the mirror chord to minimize wind loads on the drive system. The receiver/absorber is attached to the mirror drive and rotates with the unit. A glass window on the receiver reduces thermal losses.

The collector field is under the control of the system controller and individual collector controllers. System start-up is initiated by a set minimum light level and maximum wind level. At start-up each collector acquires the sun (points at the sun) and initiates tracking. The collectors track individually throughout the day. High wind or

SIMPLIFIED SYSTEM SCHEMATIC

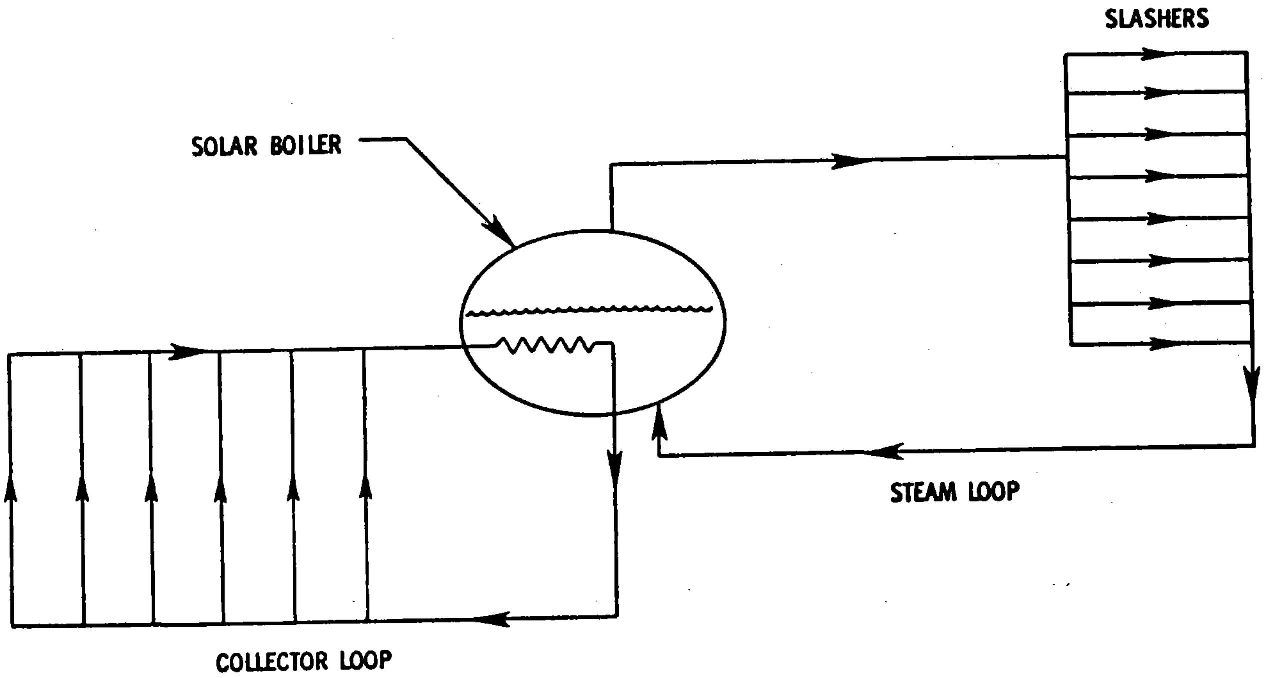


Figure 1. Simplified System Schematic

low light level will cause the system controller to command the collectors to stow. In the stowed position the mirrors look downward to protect the surface from the weather and reduce wind load on the collector support structure.

High Temperature Water Loop

The high temperature water (HTW) loop transports the thermal energy to a steam generator and includes the solar receivers. The loop is a closed system pressurized to 275 psi to allow for HTW transport without the formation of vapor (boiling). A supply header feeds the collectors from one edge of the field and a return header runs down the outer edge of the field to form a "C" loop type of flow pattern. Ball valves at the collectors are used to balance the flows in the collectors and for isolation. Design flow is 2 gpm in each collector (48 gpm system flow). The HTW loop is sloped to enhance elimination of air bubbles and contains manual air vents, an air trap, and an air eliminator. A 5 hp pump provides the 48 gpm field flow against a 22 psi head. An expansion tank allows for the daily expansion and contraction of the HTW fluid. A water-to-steam package boiler (steam generator) is fueled by the HTW and provides the process steam.

Steam Generator

The steam generator is the interface between the HTW loop and the process steam loop. It is a commercially available package boiler that generates 76 psi steam when fueled with 380°F water. Feedwater for the steam generator is taken from a steam condensate tank. The steam generator is located on the weave room roof near the collector field.

Steam Loop

The steam loop transports the solar steam from the steam generator into the building and to the process. Steam flow is controlled by a check valve that allows the solar steam to displace fossil fuel generated steam when solar generated steam is available. When solar steam is not generated, the existing steam system supplies the process steam. Completing the steam loop is the feedwater line pumped from a condensate receiver.

PERFORMANCE

The solar energy system supplies process steam at 70 psi and 317°F to the slasher manifold. Slasher operation at 5 to 60 psi is insensitive to the steam source and allows displacement of fossil fuel when under solar operation. At the system design point of 2 p.m., September 21, the system is expected to provide 1,000 lbs./hr. of steam under clear sky conditions. Based on 300 working days per year and representative weather tape data for Atlanta, Georgia, the system is expected to deliver 10^9 Btu's/year to the process.

ACKNOWLEDGMENTS

The detailed design, installation and operation of this solar application is being conducted under contract to DOE, Conservation and Solar Energy Branch, Agricultural and Industrial Process Heat Applications, Contract Number E(40-1)-5124. The Technical Project Officer at DOE is Mr. W.W. Auer. This work is being conducted by Honeywell's Energy Resources Center in Minneapolis, Minnesota and the industry partner is WestPoint Pepperell, West Point, Georgia. The Phase I Detailed Design effort and the Phase II fabrication and installation at the Fairfax, Alabama site have been completed. The Phase III data collection and system evaluation is currently underway.

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM

Stanley B. Youngblood
Acurex Corporation
Mountain View, CA

CONTRACT: DE-AC03-77-CS31713

CONTRACTOR: Acurex Corporation/Alternate Energy Division
485 Clyde Avenue, Mountain View, CA 94042

USER INDUSTRY: Johnson & Johnson
P.O. Box 5000, Sherman, TX 95090

CONTRACT PERIOD: 9/77 through 12/79

FUNDING:
Phase I: Design (10/77 to 7/78) $ 214,007
Phase II: Construction (10/78 to 10/79) $1,613,504
Phase III: Evaluation (11/79 to 3/81) $~ 200,000

PRINCIPAL INVESTIGATOR: Stanley B. Youngblood (415) 964-3200 x3530

Objective

The objective of this project is to demonstrate the technical and economic feasibility of generating industrial low pressure steam with solar energy at the Johnson & Johnson manufacturing plant in Sherman, Texas (Figure 1). Acurex has designed a system employing 1070 m^2 (11,520 ft^2) of Acurex Model 3001 parabolic trough collectors in which pressurized water circulates directly through the collector, reaching temperatures as high as 490°K (420°F) before being throttled into a flash boiler. Water in the boiler flashes to steam to supply the plant steam main. This is shown in Figure 2. Table 1 provides a summary of the design. Key features of the design include:

1) ground installation with additional land available for collector expansion
2) improved collector design to reduce installation and maintenance costs
3) simple plant interface: all solar energy is used as it is collected

Status of Project

The design for this project was completed in June 1978. Construction began in April 1979 and was completed in September 1979. Startup and checkout of the facility is scheduled for completion in November of this year. This will be followed by a 15 month evaluation of system operation and performance.

FIGURE 1. JOHNSON & JOHNSON MANUFACTURING PLANT IN SHERMAN, TEXAS

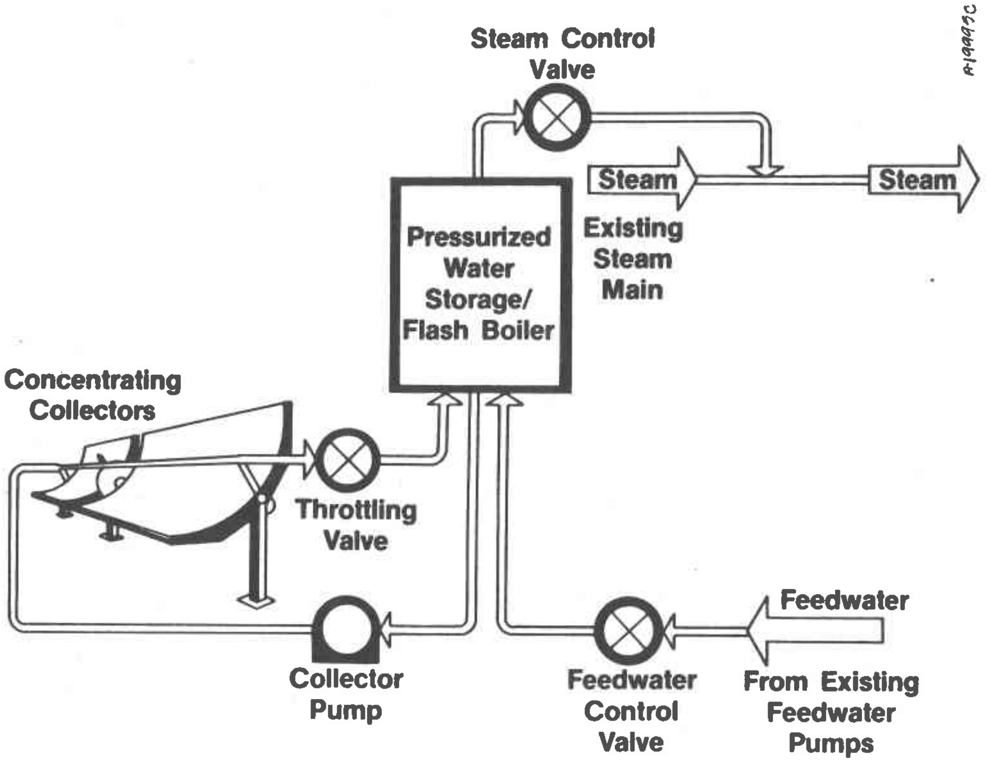


FIGURE 2. SOLAR STEAM SYSTEM SCHEMATIC

TABLE 1. SUMMARY OF JOHNSON & JOHNSON SOLAR DESIGN

Collectors:	1070 m^2 (11,520 ft^2) line focus parabolic trough (axis 45° from north/south)
Storage:	18,921 ℓ (5,000 gallon flash boiler reservoir for freeze protection)
Fluid:	Pressurized water
Supply Temperature:	445°K (345°F)
Flowrate:	3.78 ℓ/sec (60 gpm)
Annual Energy Supplied:	1.58×10^9 kJ (1.5×10^9 Btu)
Barrels of Oil Displaced:	325

Summary of Accomplishments

During this phase of the project the installation of the Johnson & Johnson solar facility was completed. Figure 3 shows the collector field and manifold piping near completion. Figure 4 shows an installed collector row. The installed flash boiler is shown in Figure 5. Figure 6 shows the installed collector field viewed toward the plant.

System Performance

Computer modeling was used to determine the annual delivered energy from the system. These results are shown in Figure 7. The system is expected to displace about 325 barrels of oil annually. The economics of this facility is depicted in Figure 8. These results indicate that a combination of investment incentives, lower installed costs, and improved system performance must be realized if solar investments are to compete with conventional fossil fuel sources.

Future Activities

Startup and checkout of the facility will be completed in November 1979, and will be followed by a 15 month period to evaluate the operation and performance of the Johnson & Johnson solar facility.

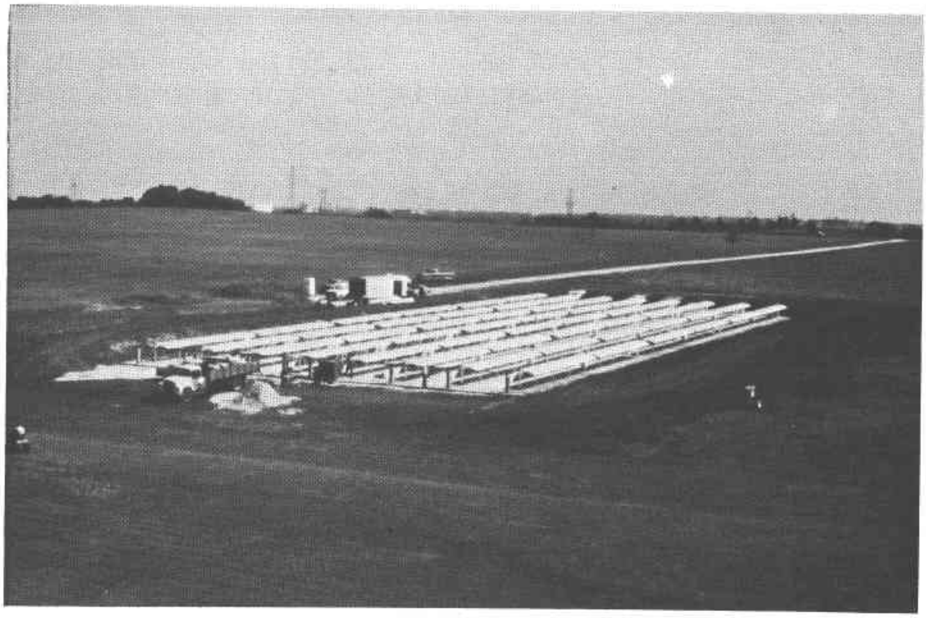


FIGURE 3. COLLECTOR FIELD AND MANIFOLD PIPING NEAR COMPLETION

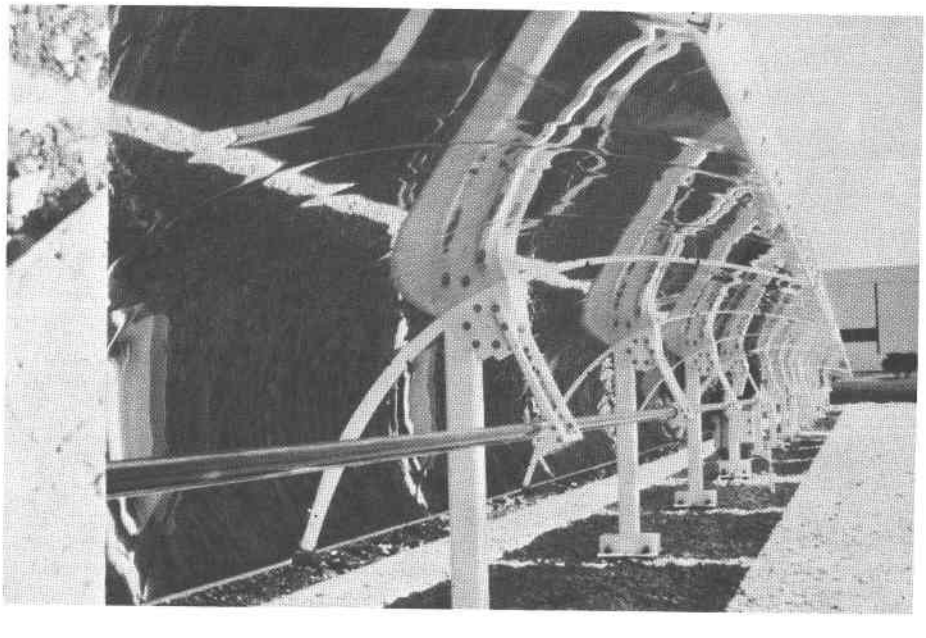


FIGURE 4. INSTALLED COLLECTOR ROW

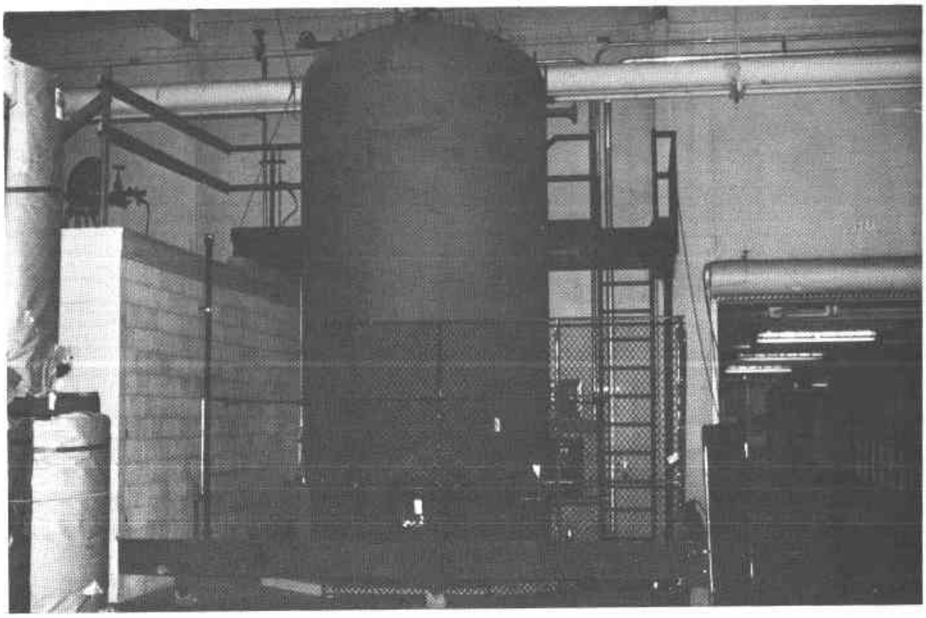


FIGURE 5. INSTALLED FLASH BOILER AT JOHNSON & JOHNSON

FIGURE 6. INSTALLED COLLECTOR FIELD VIEWED TOWARD THE PLANT

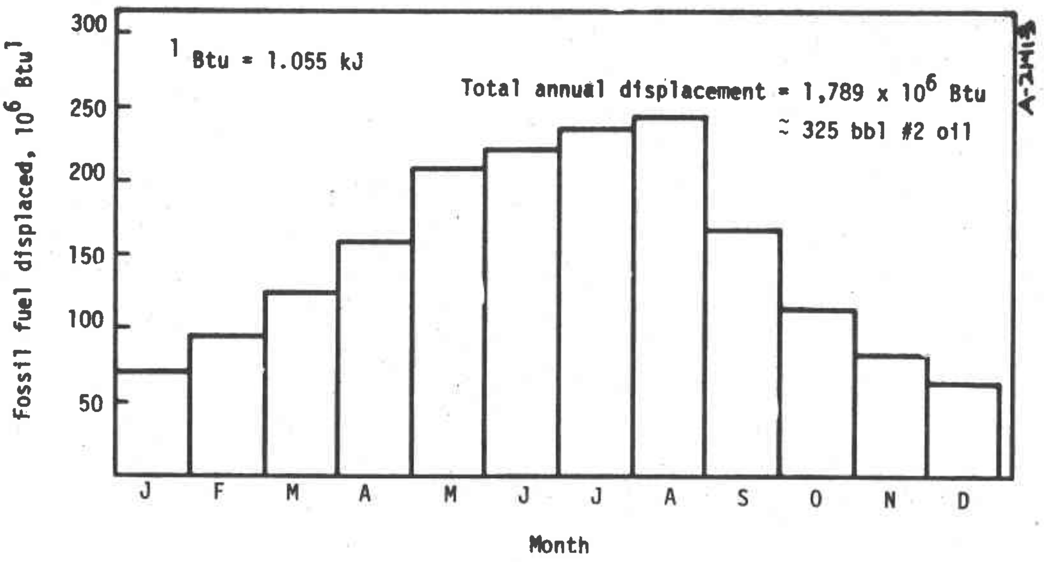


FIGURE 7. MONTHLY DISTRIBUTION OF FOSSIL FUEL DISPLACED BY SOLAR ENERGY SYSTEM (NET OF PARASITIC)

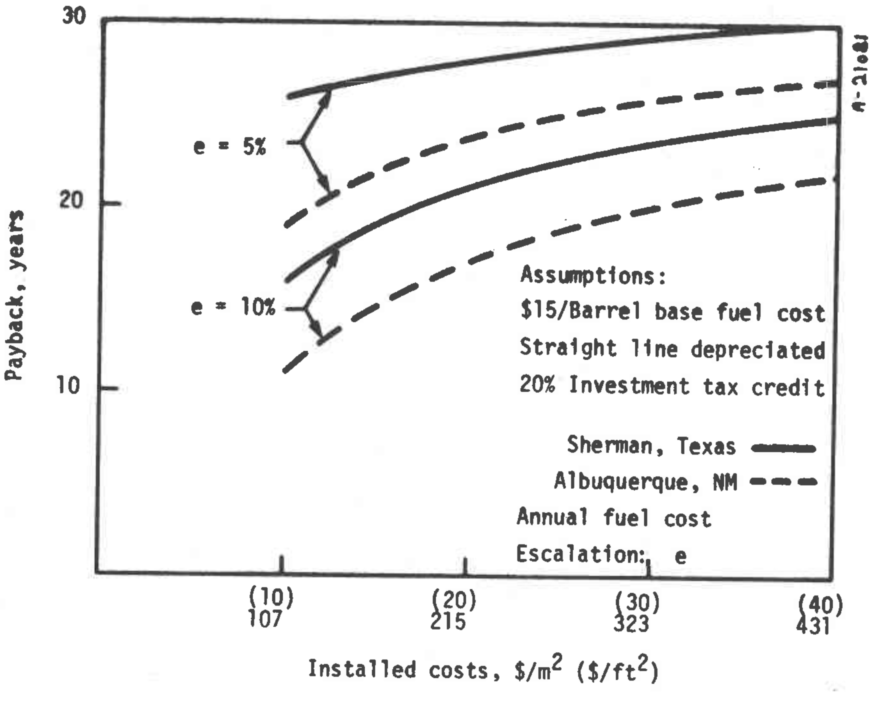


FIGURE 8. EFFECT OF INSTALLED SYSTEM AND FOSSIL FUEL COSTS ON PAYBACK PERIOD

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR THE HOME LAUNDRY

B. G. Eldridge
Jacobs-Del Solar Systems Inc.
Pasadena, California

ABSTRACT

Commercialization of solar energy for industrial purposes is an attractive goal in light of current concern over air pollution and the availability and cost of fossil fuels. A project at The Home Laundry in Pasadena, California, has been designed to demonstrate the technical and economic feasibility of utilizing a solar system in a process heat application. This Jacobs-Del project is currently under construction and will be operational by February 1980. The principal problem encountered in connection with the project to date has been of an institutional nature; in the State of California, property taxes on a solar system often exceed the dollar value of any fuel savings. Recommendations for legislative reform on this issue have now been formulated for proposal to the State of California.

OBJECTIVES OF THE PROJECT

Innumerable potential uses for solar energy in process heat applications (chiefly, steam) exist in the commercial sector. Laundries, restaurants and film processors are particularly likely candidate-users for solar systems. The U. S. laundry industry alone, for instance, consumes the energy equivalent of 555 million barrels of oil annually! Successful demonstrations of the technical and economic feasibility of solar systems will be required, however, before the commercial sector will give this alternative energy source the serious consideration which it merits. Such a demonstration is The Home Laundry in Pasadena, California, a Jacobs-Del, DOE-funded project slated for completion in February of 1980. In addition to clarifying technical, economic and legal issues of interest, the project will also allow us to validate our Solar

Thermal Systems Simulation (STSS) model.

The Home Laundry is situated in a smog-bound, metropolitan area. The installation of the solar energy system will reduce the laundry's emission of pollutants significantly--a fact which, in this location, will be highly visible to both the business community and the public. Such exposure should illustrate the promise of solar energy as a means of improving air quality while fostering industrial growth.

PROJECT DESCRIPTION, STATUS AND RECENT DEVELOPMENTS

The solar system which has been designed for The Home Laundry will meet 25 percent of the laundry's annual steam and 21 percent of its annual, combined steam and hot water requirements. It will consist of 6,496 square feet of Del parabolic-trough, concentrating collectors mounted on a lightweight steel structure. The collectors will be oriented North-South to track the sun East-West.

A close circuit solar collection loop utilizing water pressurized with nitrogen will operate at collection temperatures of 410^{o}F to transfer energy from the array to the steam generator. A buffer storage tank, when charged, will allow the system to continue to operate and to generate steam (150 psig) through small periods of transient cloud conditions. When solar energy is insufficient to generate steam, but can produce collection temperatures sufficiently high to heat hot water, this energy will be utilized to heat domestic water for use in the laundry.

The system is currently under construction and will be operational by February 1980. It will be operated for one year, during which time system performance will be monitored. Formal data acquisition will begin in February of 1980 and will continue until February of 1981. Continual system evaluation will be made during this period.

Recent changes in design and material purchases have been made to accomodate an on-site data reduction system. This data reduction system will decrease the amount of raw data to be analyzed in the project by providing statistical information on an hourly basis.

INSTITUTIONAL AND ECONOMIC ISSUES

The owner of The Home Laundry refused permission for the construction of the solar system until the question of property tax assessment was answered to his satisfaction. This prompted Jacobs-Del to research the tax topic thoroughly. Careful economic analyses were performed with a view to proposing modifications to existing tax policies. We learned that, in the State of California, property taxes on a solar system may exceed the dollar value of any fuel savings.

This situation results from the fact that solar systems are capital-intensive projects; equivalent, conventional process heat facilities require comparatively inexpensive components. Thus, the owner of a solar process heat facility must anticipate both a heavy, initial investment in his property and a heavy tax burden thereafter. By contrast, the owner of a conventional property invests less originally, then pays lower taxes. This policy clearly does not encourage interest in the solar energy alternative. A more practical taxation scheme would evaluate both solar and conventional systems in terms of their function, i.e., the value of the work they perform. The effect of current State of California tax policies is illustrated in Table I.

Other states have approached solar system property taxation in several ways favorable to the industry:

1. Solar systems are assessed at no more than comparable, conventional, fossil-fuel systems;

2. Solar systems are either partially or entirely exempted from property taxation; and

3. Rights are transferred to local governments to enact measures which exempt solar systems from property taxes.

In the State of California, a property tax exemption bill was passed in June 1978; however, this bill does not include solar energy process heat application. We would propose modifications to California laws on this subject as follows:

1. Complete or partial exemption from property taxes on solar systems.

2. Exclusion of collector costs and professional services rendered during the design and construction of solar systems when there is an assessment of solar property;

3. Compensation, by state/federal governments, of local governments which enact tax policies favorable to solar systems.

CONCLUSION

Work on The Home Laundry Process Steam Project is progressing routinely. Upon its completion in February of 1980, it will stand as good evidence of the technical and economic feasibility of commercial-sector solar energy utilization. Engineering and cost data obtained from the project will also permit improved system design and decreased system costs, thereby suggesting guidelines for further, future commercialization of process heat applications. And the nature and location of the project should heighten public awareness of the benefits of the solar energy alternate.

Operational data obtained from the solar system will be fed into an existing simulation model, STSS. This data will validate and refine this model.

Another important fringe benefit of The Home Laundry Project has been that it prompted a thorough review of tax laws pertinent to solar energy utilization. Recommendations for vital reforms of the California State property tax structure have now been formulated.

References

(1) S. B. Johnson, "State Approaches to Solar Legislation - A Survey," Solar Law Reporter, SERI Publications, Vol. 1, May/June 1979.

(2) J. H. Ashworth, "Implementing Solar Financial Incentives: The Experience of State Programs," Solar Law Reporter, SERI Publications, Vol. 2, July/August 1979.

(3) S. Sundarah and B. G. Eldridge, "Institutional Constraints in Commercializing Solar Energy for Process Heat Applications," Proceedings, 45th International Conference on Assessment Administration, Las Vegas, Nevada, October 21-October 24, 1979.

TABLE I

THE HOME LAUNDRY SOLAR FACILITY: FIRST-YEAR FUEL COST SAVINGS vs. PROPERTY TAXES AS THEY WOULD VARY UNDER ALTERNATE TAX STRUCTURES

PROPERTY VALUE SUBJECT TO TAXATION	RESULTANT PROPERTY TAX	DOLLAR VALUE OF FIRST-YEAR FUEL SAVINGS[2]	
		Natural Gas	Fuel Oil
Current State of California Standard: 100% of Value of Home Laundry Solar Property Taxable. $650,000	$8,125	$4,800	$10,008
Current State of California Standard: 100% of Value of "Typical Industrial" Solar Property Taxable. $400,000[1]	$5,000	$4,800	$10,008
Current State of George Standard: 5% of Value of Home Laundry Solar Property Taxable. $ 32,500	$ 405	$4,800	$10,008
Current State of Illinois Standard: No Taxes on Solar Property -0-	-0-	$4,800	$10,008
Current State of New Hampshire Standard: Collector Costs Excluded from Value of Taxable Home Laundry Solar Property. $450,000	$5,625	$4,800	$10,008

1. The value of The Home Laundry Solar Facility exceeds this "typical" value because an expensive steel support structure and a sophisticated data base system were incorporated at The Home Laundry.

2. Values shown are based on site-specific insulation data; dollar value of fuel savings was computed based on natural gas prices at $0.24/therm and fuel oil prices at $0.50/gallon. Prices, and hence savings will actually vary for the states of Georgia, Illinois and New Hampsire.

PROPERTY TAXES ON HOME LAUNDRY SOLAR FACILITY vs. PROPERTY TAXES ON EQUIVALENT CONVENTIONAL PROCESS STEAM SYSTEM

PROPERTY VALUE SUBJECT TO TAXATION	PROPERTY TAXES
Home Laundry Solar System: $650,000	$8,125
Typical Industrial Solar System: $400,000	$5,000
Equivalent Conventional System: $ 80,000	$1,000

SOLAR PRODUCTION OF LOW PRESSURE STEAM FOR PROCESSING OF ORANGE JUICE

J.B. Trice, et.al.
General Electric Company
King of Prussia, PA

ABSTRACT

Fabrication of the system components is in process, and initial installation operations are underway at the Bradenton, Florida plant site. Construction is expected to be completed in January 1980. Following startup and checkout, a 15 month evaluation phase is currently planned to obtain data for quantifying system performance.

The principal use of the solar energy is for thawing large blocks of frozen orange juice held in cold storage at Tropicana. During weekends, when the thawing operation is shut down, the collected energy will be used to remove moisture from a glycol concentrator and for cold storage refrigeration. With this dual usage, the need for thermal energy storage is eliminated, resulting in a simpler and less expensive system.

The General Electric non-tracking concentrator (2.9:1) collector was selected for this application in order to provide the simplest, most reliable collector for the temperature required.

Instead of a continuous tracking system, the collector is manually adjusted four times a year to an appropriate tilt angle. This results in an overall efficiency that is within 2% of that which could be obtained by single axis continuous tracking. The collector area is 929 square meters (10,000 square feet).

PROJECT IDENTIFICATION

- Title - Solar Production of Industrial Process Steam for Processing of Orange Juice
- Contract No. - DE-AC03-77CS31714
- Contractor - Advanced Energy Programs
  General Electric Company
  King of Prussia, PA

- User Industry - Tropicana Industries
  Bradenton, Florida

- Contract Data -

PHASE	TIME PERIOD	FUNDING
I - Design and Analysis	Oct'77-July'78	$ 235,453
II - Fabrication & Installation	Oct'78-Jan '80	1,074,382
III - Systems Operation and Data Collection	Feb'80-April '81	200,000 (est.)

OBJECTIVE

The primary objective of this program is to design, install and evaluate a solar energy system for industrial low pressure process steam applications. The installation at the Tropicana Industries orange juice processing plant affords an excellent opportunity to disseminate program results throughout the citrus industry and reach other industrial users of process steam.

CURRENT PROJECT STATUS

The design of the system was initiated in October 1977 and was completed in July 1978. The program is now in Phase II, System Construction, and is about 40% complete. Current planning calls for operation to begin in February 1980.

The principal use of the solar-generated steam will be to thaw large blocks of orange juice held in cold storage at -32°C (-25°F). Tropicana processes juice throughout the year and stores the juice from oranges during a nine-month harvest cycle. The juice processing line is in operation for five days per week. During the weekends the solar energy collected will be used to remove moisture from a cold storage refrigeration room. Since all of the steam is used as it is generated, there is no need for a thermal energy storage system.

The system design includes a heat exchanger through which primary collector loop fluid (treated water) circulates at 149°C - 204°C (300°F-400°F). No freeze protection is required in the Bradenton area, but provisions have been made to supply heat to the primary loop from the boiler in the unlikely event of a freeze.

The collector fluid is used to boil water in a 66 liter (250 gallon) ASME rated tank. The steam line from this solar heated boiler carries steam to the two processes, the orange juice block freezing and thawing process, and the glycol concentrator located about 366 meters (1200 feet) from the solar boiler. The General Electric non-tracking concentrator (2.9:1) was selected for this application in order to provide the simplest, most reliable collector for the temperature required. Analysis indicates that the expected overall collector efficiency is within 2% of that obtained by continuous tracking. The collector tilt positions for summer and winter seasons are shown in Figure 1. Also shown in the figure is a stowage position to protect the collector tubes and reflective surfaces from unusual weather, such as tropican storms.

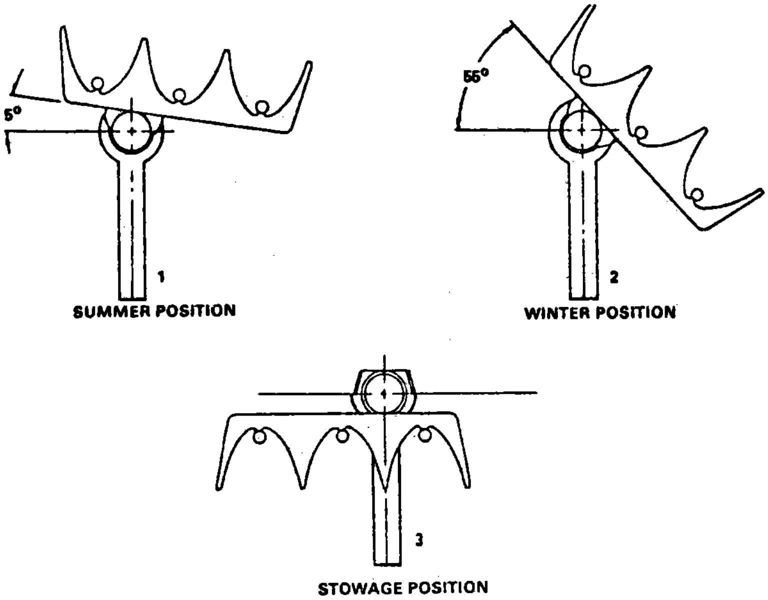


FIGURE 1. GENERAL ELECTRIC TC-300 CONCENTRATING COLLECTOR - TILT POSITIONS FOR TROPICANA INSTALLATION

SUMMARY OF RECENT ACCOMPLISHMENTS

In June of 1979 a General Contractor was selected to prepare the Tropicana site and perform the solar system installation. Fabrication of the TC-300 collector is in process at the General Electric facility in King of Prussia, PA. Fabrication of controls and instrumentation has been completed. These units are completing final checkout tests prior to shipment to the plant site.

PLANNED ACTIVITIES FOR THE NEXT SIX MONTHS

During this time period all equipment will be delivered to Bradenton, Florida, and the General Contractor (Tampa Mechanical) will install the system. Construction is currently scheduled for completion in January 1980. Following the installation, the system will be checked out prior to proceeding with the data acquisition and evaluation activities. It is currently planned to operate the system over a fifteen month system evaluation period.

Intermediate Temperature Steam

APPLICATION OF SOLAR ENERGY FOR THE GENERATION AND SUPPLY OF INDUSTRIAL PROCESS LOW TO INTERMEDIATE PRESSURE STEAM RANGING IN TEMPERATURE FROM 300°F -- 550°F

A. Ken Yasuda
Acurex Corporation
Mountain View, CA

CONTRACT:	ET-78-C-03-2196
CONTRACTOR:	Acurex Corporation/Alternate Energy Division 485 Clyde Avenue, Mountain View, CA 94042
USER INDUSTRY:	ERGON, Inc. Mobile Bulk Terminal P.O. Box 1981, Mobile, AL 36601
CONTRACT PERIOD:	9/30/78 through 6/30/79
FUNDING:	Phase I: $163,895
PRINCIPAL INVESTIGATOR:	Marx A. Matteo (415) 964-3200 A. Ken Yasuda John I. Kull

Objective

The objective of this project is to demonstrate the technical and economic feasibility of generating high temperature (300 to 550°F) industrial process heat. In this application, solar energy is used to heat No. 6 oil stored in a 120,000 barrel bulk storage tank. Heating is required to reduce the viscosity of the oil so it can be pumped into and out of bulk storage. ERGON is currently firing fossil fuels to provide the required 450 to 535°K (350 to 500°F) process heat. This process is an excellent thermal application for solar energy, and has widespread applicability in the oil industry. The system design combines off-the-shelf hardware with a simple plant interface that results in minimum installed and operating costs.

Status of Project

Phase I (design and analysis) of this project was completed in June 1979. Additional funding for construction has not been awarded.

Summary of Design

This solar system was designed to heat No. 6 oil stored at ERGON's Mobile, bulk terminal. Figure 1 shows the process site, and the proposed collector site. The system design circulates a heat transfer oil in a closed loop directly from the collector field to heat exchangers immersed in the storage tank. This is illustrated in Figure 2. Table 1 is a summary of system details.

FIGURE 1. ERGON'S MOBILE BULK TERMINAL

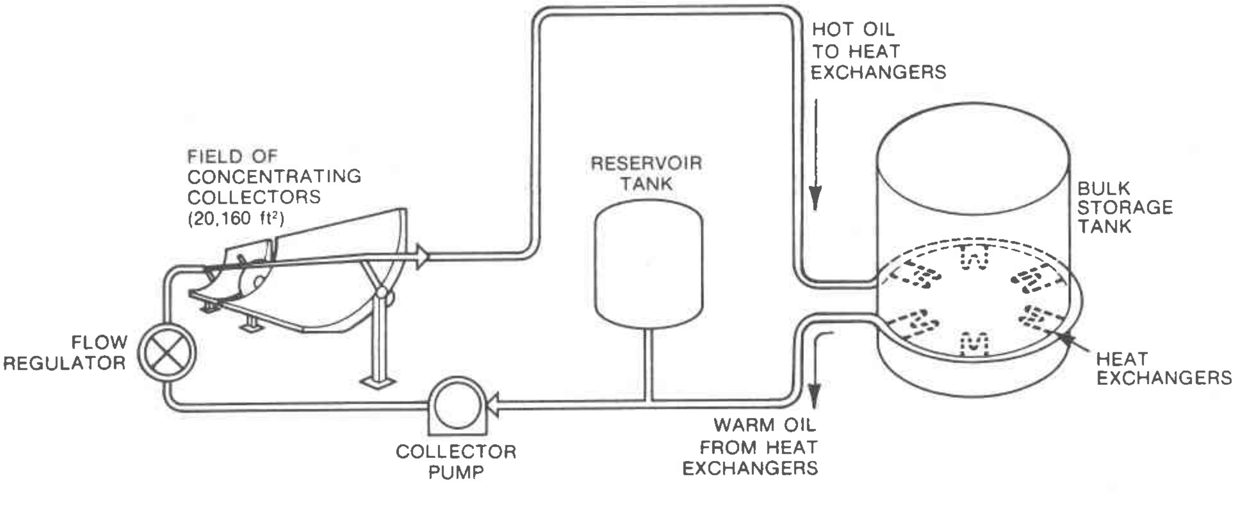


FIGURE 2. ERGON, INC. INDUSTRIAL PROCESS HEAT SYSTEM SCHEMATIC

TABLE 1. SUMMARY OF ERGON SOLAR PROCESS HEAT DESIGN

Collectors: 1874 m^2 (20,160 ft^2) Acurex Model 3001 parabolic trough concentrators

Storage: None (provided by process)

Working Fluid: Synthetic Heat Transfer Oil (Therminol 55)

Flowrate: 265 ℓ/min (70 gpm)

Supply Temperature: 365 to 535°K (200 to 500°F)

Control Mode: Constant flowrate

The collectors (Figure 3) are arranged in seven parallel flow loops. A constant flow centrifugal pump circulates the heat transfer oil through the collector field and the fin-tube heat exchangers. The heat exchangers already exist and are presently used for heating the tank. A key feature of this design is that thermal storage is provided by the process itself. The storage tank must be maintained at a minimum temperature of 54°C (130°F), and cannot exceed 88°C (190°F). This provides thermal storage for the system during low insolation periods.

An important criteria during system design was to minimize the life cycle cost of energy supplied. This led to a system design using heat transfer oil as the working fluid. Two other concepts were studied, but found to be less cost-effective. One alternative circulated pressurized water in the collector field that flashed to steam for use in the heat exchangers. The other concept circulated a heat transfer oil through the collector field and an unfired steam generator produced steam for the heat exchangers. The costs for all three alternatives were within six percent of one another, but the net energy supplied varied widely. This is illustrated in Figure 4. Note that each system was evaluated for different collector field sizes. The final system design was optimized for both field size (20,160 ft^2) and flowrate (70 gpm).

System Performance

System performance was evaluated using an Acurex computer code (SOLTHERM). The solar system is expected to supply 2.69×10^9 kJ/yr (2.55×10^6 Btu/yr) to the process. This is 44 percent of the annual process heat load and is equivalent to about 660 barrels of oil. During peak insolation periods, the system will generate 960 kW_{th} (3.2×10^6 Btu/hr). A summary of annual system performance is shown in Figure 5.

The effect of installed solar costs and investment tax credits is illustrated in Figure 6 for two locations: Mobile, Alabama and Albuquerque, New Mexico. These results indicate that both investment tax credits and geographical location significantly affect the simple payback period for the solar investment. Investment tax credits in effect reduce installed costs. Moreover, Albuquerque achieves approximately 70 percent more fossil fuel savings than Mobile due to greater annual insolation.

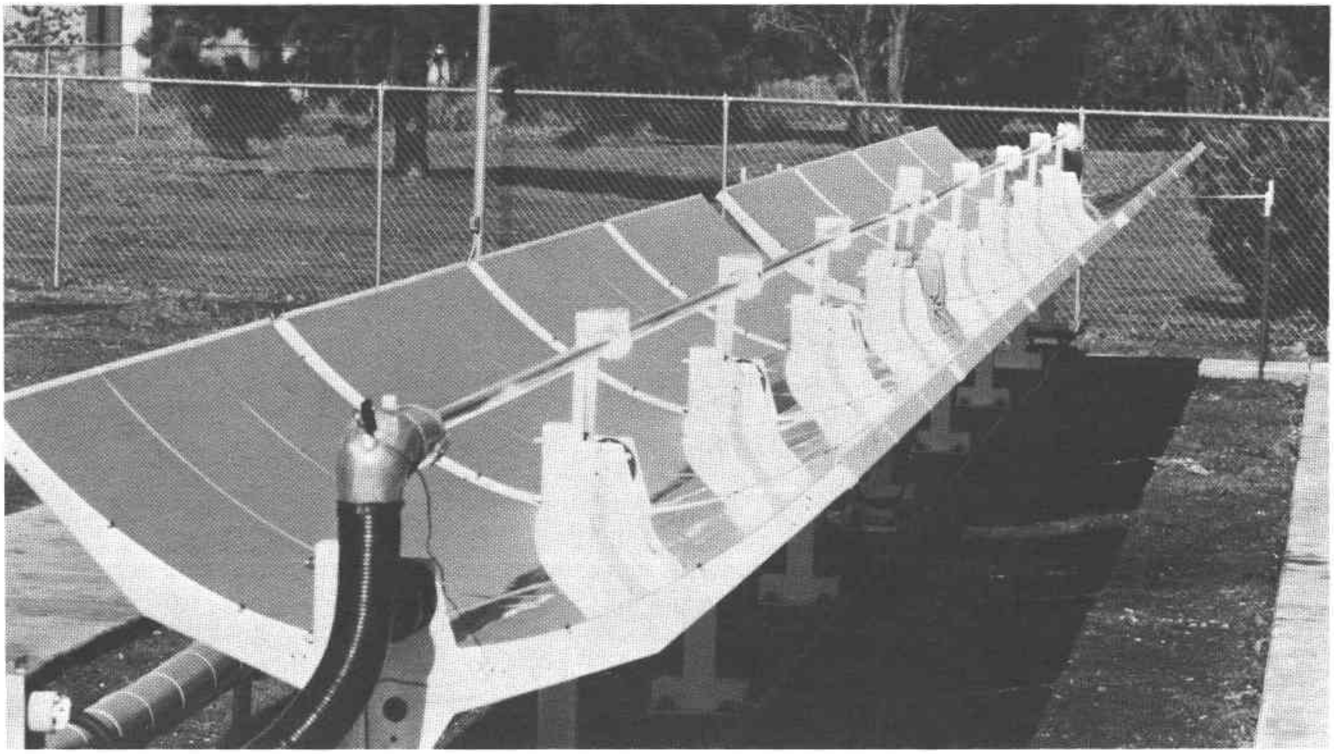
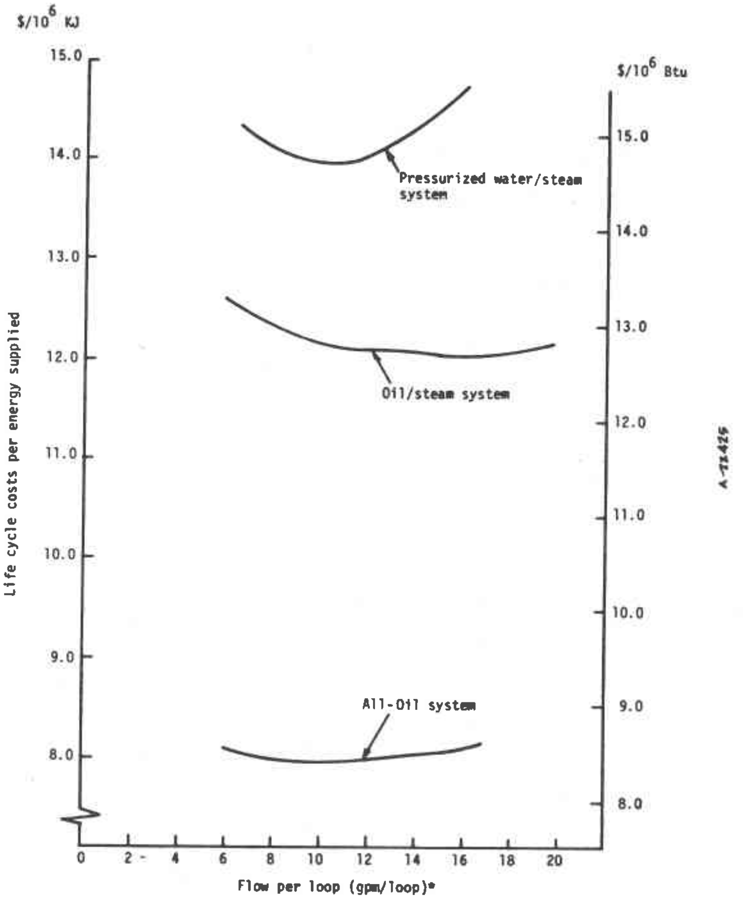


FIGURE 3. COLLECTORS ARRANGED IN SEVEN PARALLEL FLOW LOOPS



*gpm = $6.31 \cdot 10^{-5}$ m^3/s

FIGURE 4. COMPARISON OF THREE POTENTIAL SYSTEM CONFIGURATIONS

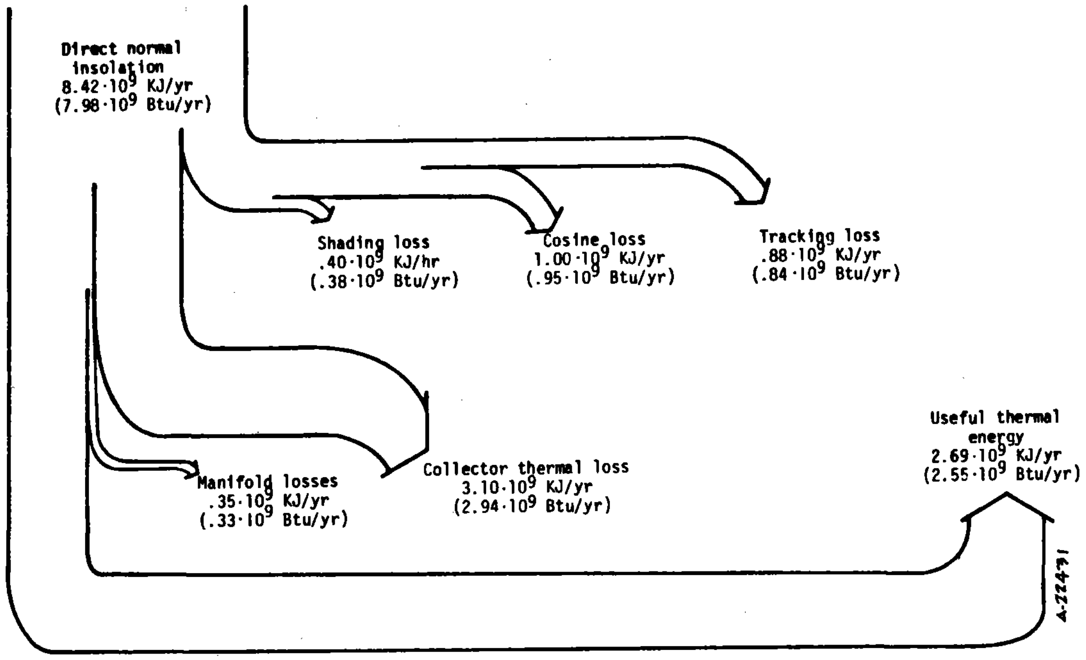


FIGURE 5. ANNUAL ENERGY FLOW DIAGRAM

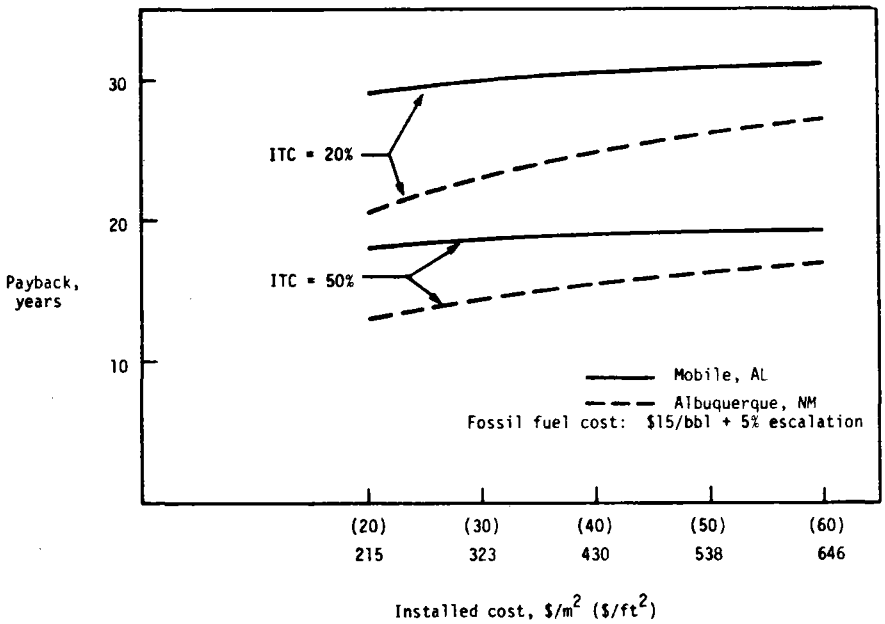


FIGURE 6. EFFECT OF INSTALLED COST AND INVESTMENT TAX CREDIT ON PAYBACK PERIOD

The costs of solar derived energy is compared with fossil fuel and electricity costs in Figure 7 for two solar investment tax credits. For this comparison, costs are expressed in terms of dollars per equivalent fossil Btu's. This figure indicates that installed solar costs must be less than $30/ft^2 for a 20 percent investment tax credit to be competitive with electricity. With a 50 percent investment tax credit, the solar costs are always less than electricity. Fossil fuel costs, however, are lower than solar costs for both the 20 and 50 percent investment tax credit assumptions over the range of installed solar costs. Availability of fossil fuels, however, may prove more critical than price alone. In conclusion, a combination of investment incentives (e.g., investment tax credits), lower installed costs, and improved system performance must be realized if solar investments are to compete with conventional fossil fuel sources.

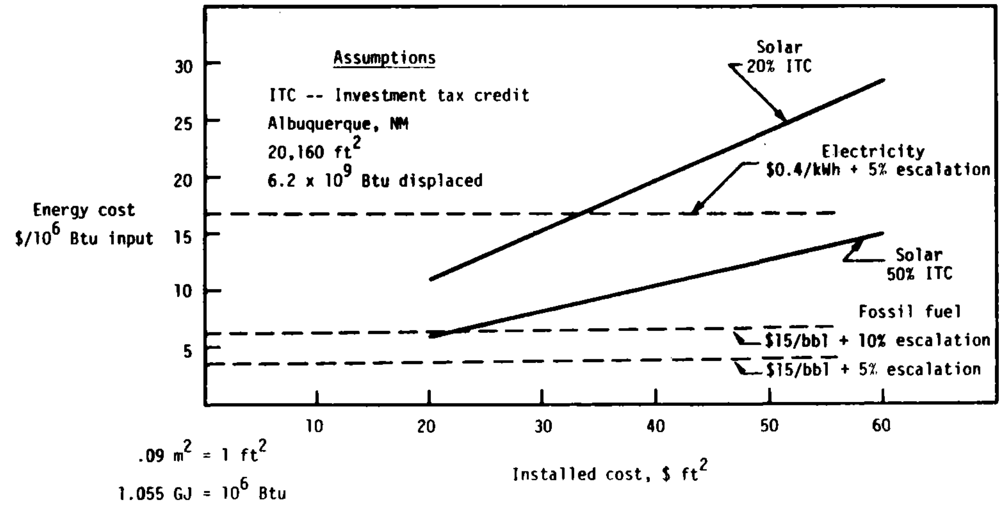


FIGURE 7. COMPARISON OF FOSSIL FUEL AND ELECTRICITY COSTS WITH SOLAR COSTS

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM AT DOW CHEMICAL COMPANY'S DALTON, GEORGIA, LATEX MANUFACTURING PLANT

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ABSTRACT

This solar system is designed to generate industrial process steam at 1034 kPa (150 lb/in^2) gage for Dow Chemical Company's Latex Manufacturing Plant in Dalton, Georgia. The project, funded by the U.S. Department of Energy, is intended to develop a demonstration unit consisting of 929 m^2 (10,000 ft^2) of solar collector surface area. Dowtherm LF is used as the intermediate heat-transfer fluid which is circulated in the primary loop through Suntec-Hexcel parabolic trough collectors to a boiler and then back to the collectors via a circulating pump. The system is expected to generate 2677 GJ (2536 x 10^6 Btu) annually.

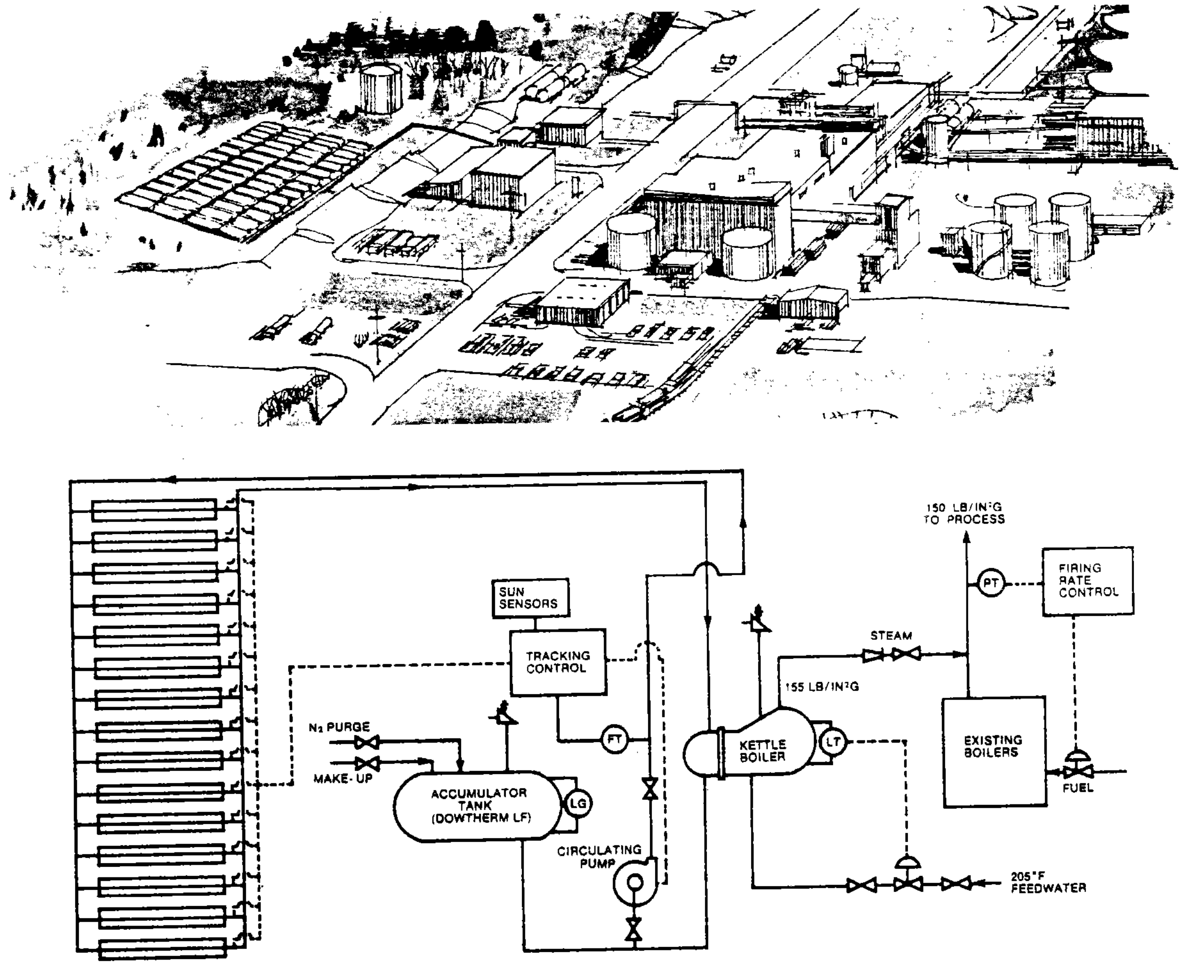

FIGURE 1 ARTIST'S CONCEPTION AND SCHEMATIC OF SOLAR STEAM SYSTEM AT DOW'S DALTON PLANT

INTRODUCTION

Work on this solar industrial process steam project began on September 30, 1978. The primary objective of Phase I (Contract No. ET-78-C-03-2199), was to design a cost-effective solar steam generating system. Other objectives were to predict system performance; conduct a safety evaluation, environmental impact assessment, and economic analysis; and promote the project to industry and the general public.

Phase I work was completed on June 30, 1979, and a final design report was submitted to DOE. Funding for Phase I was $194,000. No major problems were encountered during the design and analysis phase of the project.

Work on Phase II - Fabrication and Installation (Contract No. DE-AC03-78CS32199), began on September 30, 1979. During this phase, the solar steam plant will be fabricated and installed in accordance with the approved design and performance specifications developed under the Phase I contract. Fabrication and installation is expected to be completed by September 30, 1980. Funding for this phase is $801,098.

SYSTEM SUMMARY

The solar process steam system shown in Figure 1 has the following features:

- System Description - The heat-transfer fluid circulates through the collectors and boils water in a kettle boiler to produce steam. An accumulator tank connected to the fluid loop serves both as an expansion tank and dump tank. No overnight freeze protection is required.
- Collector - Suntec-Hexcel parabolic trough collector manufactured by Suntec Systems, Inc.; sun-hour tracking; north-south orientation with 10-deg tilt facing south; 15 rows; 923 m^2 (9930 ft^2) collector area; smooth absorber tube with smooth inner plug.
- Storage - None required.
- Boiler - Kettle type; boiler surface area 23 m^2 (250 ft^2); fitted with pressure relief valve, low-level alarm, and level transmitter to feedwater flow-control valve.
- Circulating Pump - Centrifugal, with single-speed 2.24 kW (3-hp) motor.
- Accumulator Tank - 1.2 m (4 ft) diameter x 2.4 m (8 ft) long; fitted with pressure relief valve, level gage, and low-level alarm; nitrogen purge.
- Heat-Transfer Fluid - Dowtherm LF manufactured by Dow Chemical Company.

- **Piping***
  - Collector inlet: 50 mm (2 in.) Sch. 40
  - Collector outlet: 50 mm (2 in.) Sch. 40
  - No heat tracing
  - Feedwater piping: 25 mm (1 in.) Sch. 40
  - Steam outlet piping: 76 mm (3 in.) Sch. 40
- **Design Conditions**
  - Dowtherm LF
    - Boiler inlet temperature: 265°C (510°F)
    - Boiler outlet temperature: 190°C (375°F)
    - Fluid flow rate: 0.22 m^3/min (57 gal/min)
    - Nitrogen pressure: 207 kPag (30 lb/in^2g)
  - Steam/Water
    - Feedwater inlet temperature: 95°C (205°F)
    - Steam outlet pressure: 1034 kPag (150 lb/in^2g)
    - Peak steam flow rate: 680 kg/h (1500 lb/h)
- **Thermal Performance**
  - Annual thermal collector output: 2998 GJ (2842×10^6 Btu)
  - Annual piping thermal losses: 186 GJ (176×10^6 Btu)
  - Annual thermal losses from overnight cooling: 137 GJ (130×10^6 Btu)
  - Annual parasitic losses in collector tracking motors and automatic control system: 472 GJ (447×10^6 Btu) electric
- **Solar Steam Production**
  - Annual thermal energy available for steam production: 2677 GJ (2536×10^6 Btu)
  - Estimated annual solar steam production: 1.1×10^6 kg (2.5×10^6 lb)
  - Percentage of steam supplied by solar steam system:
    - At peak solar conditions: 37.5
    - Annual: 7.1

---

*Restriction orifices are installed on the absorber risers near the inlet manifold.

THE SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM
(NL Industries, Inc. Project; Newberry Springs,California)

B. G. Eldridge
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Pasadena, California

ABSTRACT

A concept design analysis was performed to evaluate the technical and economic feasibility of the solar production of industrial process steam for an NL Industries, Inc. project at Newberry Springs, California. A solar system was proposed which included 10,240 sq.ft. of Del, single-axis, tracking, parabolic-trough, concentrating collectors. Potential problems with system freezing and collector maintenance were anticipated and skirted. It is estimated that implementation of this system would result in an annual savings of 3,356 BTU, or the equivalent of 600 barrels of oil.

INTRODUCTION

The NLI facility at Newberry Springs processes hectorite ore. Hectorite is a hydrous magnesium silicate which, when refined, is of significant commercial interest because of its applications in various chemical and food processes. The refinement process includes a drying operation which reduces the moisture content of the product to 4%. Medium-pressure steam of 160 psi is utilized in this process. The implementation of a solar energy system to produce a portion of the 300°-550° F. steam required would provide a useful demonstration of the feasibility of the solar production of industrial process steam, and the facility's Mojave Desert location makes it an ideal site for solar studies. For these reasons, in response to a DOE RFP, Jacobs-Del Solar Systems, Inc. explored various solar energy systems for NLI to determine which would be the most cost effective on a $/BTU basis.

CONCEPT DESIGN ANALYSIS

Our original proposal was for a base system consisting of 15,360 sq.ft. of Del collectors installed on a 15° tilt angle. At this time, we anticipated that a new Del collector with a two-meter aperture and an evacuated receiver tube would be designed and ready for production in January of 1980. (Unfortunately, the development program for this collector slipped one to two years)

Several alternatives to the base system were also offered.

Alternate No. 1

This originally-proposed base system consisted of 960, 8'-0 length, 24" aperture DEL collectors: 15,360 sq. ft. of collector area. Annual, usable solar energy for the 15° tilt angle = 5,016 MMBTU.

Alternate No. 2

This scheme consisted of 960 collectors (as in Alternate No. 1), but included four array modules of 240 collectors each, for an area of 3,840 sq. ft. Annual usable solar energy for the 15° tilt angle = 5,016 MMBTU.

Alternate No. 3

This alternative included 360 collectors with apertures of two meters and unit lengths of 10'-0", providing a total of 21,600 sq. ft. of collector surface. Annual usable solar energy for the 15° tilt angle - 10,539 MMBTU.

Alternate No. 4

This was a slightly different configuration that promised lower installation costs and required 378 collectors, for a total collector area of 22,680 sq. ft. Annual usable solar energy for the 15° tilt angle = 11,458 MMBTU.

Alternate No. 5

This proposal was similar to No. 4; it consisted of 17,280 sq.ft. of collector area, however. Annual usable solar energy for the 15° tilt angle = 9,166 MMBTU.

The vital statistics on each of these alternatives are summarized for comparison in Table 1.

Alternative	Area of Array (Sq.Ft.)	Usable Solar MMBTU	Est. Construction Cost	Unit Costs	
				$/Sq.Ft.	$/MMBTU
1	15,360	5,016	$803	52	160
2	15,360	5,016	781	51	156
3	21,600	10,539	886	41	84
4	22,680	11,458	873	39	76
5	17,280	9,166	764	44	83

TABLE 1

To conform to DOE budgetary limitations, however, it became necessary to modify the suggested base system. The new design reduced the array to 10,240 sq. ft. of collectors installed on a 7.5° tilt angle. A supplementary analysis was then conducted to evaluate variations of this new smaller system.

Alternate No. 1	(a)	Collectors:	DEL 2'-0 aperture with non-evacuated receiver tube
	(b)	Orientation:	N - S on berms sloping south at 7-1/2°
Alternate No. 1	(a)	Collectors:	DEL 2'-0 aperture with an evacuated receiver tube
	(b)	Orientation:	N - S on berms sloping south at 7-1/2°
Alternate No. 3	(a)	Collectors:	DEL 2'-0 aperture with non-evacuated receiver tube
	(b)	Orientation:	N - S, horizontal (no tilt)
Alternate No. 4	(a)	Collectors:	DEL 2'-0 aperture with evacuated receiver tube
	(b)	Orientation:	N-S, horizontal (no tilt)
Alternate No. 5	(a)	Collectors:	DEL 2'-0 aperture with non-evacuated receiver tube
	(b)	Orientation:	E - W, horizontal
Alternate No. 6	(a)	Collectors:	DEL 2'-0 aperture with evacuated receiver tube
	(b)	Orientation:	E - W, horizontal
Alternate No. 7	(a)	Collectors:	Solar Kinetics 7'-0 aperature, non-evacuated receiver tube
	(b)	Orientation:	E - W, horizontal

Alternate No. 8 (a) Collectors: Acurex 6'-0 aperture, non-evacuated receiver tube
(b) Orientation: E - W, horizontal

These eight alternatives are compared in Table 2.

Alternative	Collector	Tilt Angle	Usable Solar MMBTU	Est. Cost	Unit Costs $/Sq.Ft.	Unit Costs $/MMBTU
1	DEL (Std)	7.5°	3,168	638	62	201
2	DEL (Vac)	7.5°	4,408	708	67	161
3	DEL (Std)	0	2,872	594	58	207
4	DEL (Vac)	0	4,000	664	65	166
5	DEL (Std)	0*	2,728	576	56	211
6	DEL (Vac)	0*	3,800	646	63	170
7	Solar Kin.	0*	2,728	553	54	190
8	Acurex	0*	2,592	635	62	245

TABLE 2

*E-W orientation - Others N-S

Note: The calculated performance for Acurex and Solar Kinetics was based on preliminary information only and not on actual performance data.

An in-depth study proved that the pump-down vacuum tube system required further development before implementation/use. Table 2 indicates that the Solar Kinetics collector might provide the most cost effective system on a $/BTU basis for collectors with standard receiver tubes. However, we consider the Del collector superior--certainly so for the desert location--due to the glass reflective surface. In this respect, the Del collector with the standard receiver tube (Alternative #1) was considered the best option and was selected as the basis for the final design.

SYSTEM DETAILS

The solar system which Jacobs-Del ultimately designed for NLI consists, as previously stated, of 10,240 square feet of Del, single-axis, tracking, parabolic-trough, concentrating collectors. The collectors are divided into four groups of 160 collectors each, positioned on a 7.5° tilt, facing south, to maximize the annual collection of energy by reducing end and cosine losses. Eight collectors comprise the delta temperature strings; the drive string includes 32 collectors. All collectors and piping are supported on concrete piers. Figure 1 shows a solar steam flow diagram.

The solar energy collection loop is a closed-circuit piping system, pressurized with nitrogen. A circulating pump circulates the heat transfer fluid from the solar array to a steam generator, then back to the solar array. Because of its high heat transfer characteristics, water is to be used as the heat transfer fluid. The system is designed to produce hot water at a temperature of 450° F and at a pressure of 420 psig.

Solar energy will not be stored at high temperatures at the NLI facility. When possible, it will be utilized, as collected, to generate steam. When there is insufficient solar energy for the generation of steam, the low-grade solar energy will be collected and used to heat water in a 24,000 gallon process hot water storage tank. Thermal energy recovered from the jacket cooling system will also be utilized in the process hot water storage tank.

The current system at Newberry Springs employs a boiler, fired with natural gas, to produce steam; fuel oil is used when the natural gas is interrupted. The steam is fed directly to drum dryers. Condensate from the drum dryers is returned to a dearator, from which boiler feed water is supplied to the boiler.

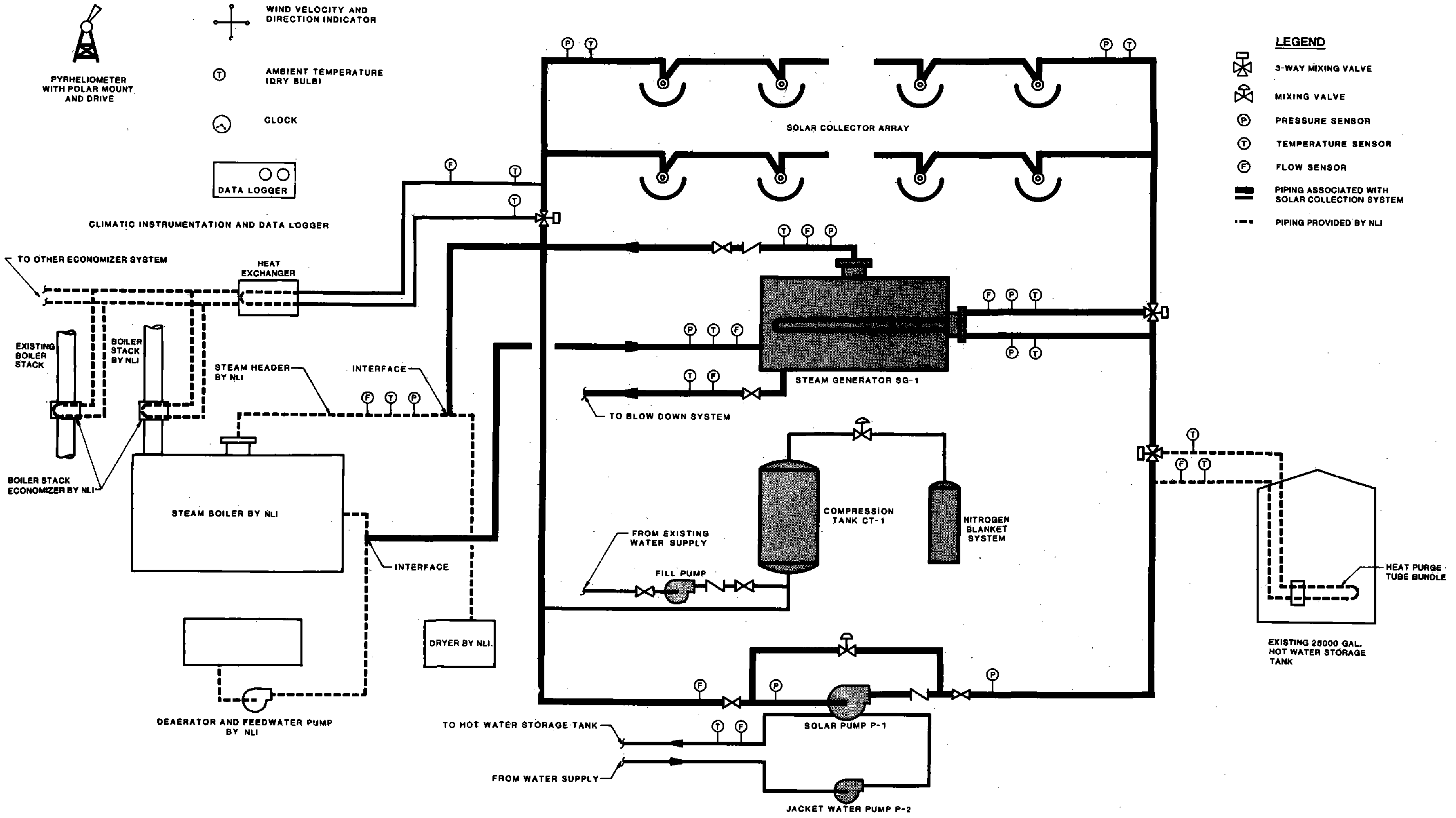
A flue stack economizer on the existing 21,000 lb/hr. boiler will provide waste heat energy to the new solar system. In addition, a new heat exchanger will recover waste heat energy to increase the efficiency of the solar energy system. The economizer will preheat the process hot water and the feed water for the boiler.

Most operations at the Newberry plant run 24 hours a day; the steam drum drying facility, however, is a 12-hour/day, 363 day/year operation. Waste heat, which will always be available from the economizer, will be utilized to preheat the solar collection system in the early morning hours. This will allow early steam generation with solar energy and will avoid a warm-up period, the length of which would ordinarily be determined by ambient temperature and the availability of solar radiation. The waste energy will be used, also, to replace the energy in the solar system which will be lost during hours of cloud cover or at night.

Two potential problems have been anticipated and remedied. First, freezing could occur during the winter months; waste heat from the economizer, or hot water from the storage tank will provide freeze protection. Second, collector maintenance and cleaning could be complicated by fine dust blown across the site from an ore storage area west of the system; this storage area has been relocated.

CONCLUSIONS

The proposed solar system would provide a useful demonstration of the feasibility of the solar production of industrial process steam. It would also result in an annual savings of 3,356 million BTU, or the equivalent of 600 barrels of oil, for NL Industries.



SOLAR STEAM GENERATED FLOW DIAGRAM

NOT TO SCALE

Jacobs-Del Solar Systems, Inc.
A Member of Jacobs Engineering Group

N. L. INDUSTRIES INC. 14-8142
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ENERGETICS CORPORATION
The Energy Company

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A HIGH TEMPERATURE PROCESS STEAM APPLICATION

AT THE

SOUTHERN UNION REFINING COMPANY

(SOLAR ENERGY IN THE OIL PATCH)

SUBMITTED BY:

ENERGETICS CORPORATION
833 E. Arapaho Road, Suite 202
Richardson, Texas

SUMMARY

The desires of the Department of Energy with respect to the Southern Union Refining Company's Solar Production of Industrial Steam, as expressed in Contract #EM-78-C-03-2223 with Energetics Corporation have been essentially satisfied. This Phase I Design for an Industrial Process Heat program has moved smoothly to completion while remaining within schedule and cost plans.

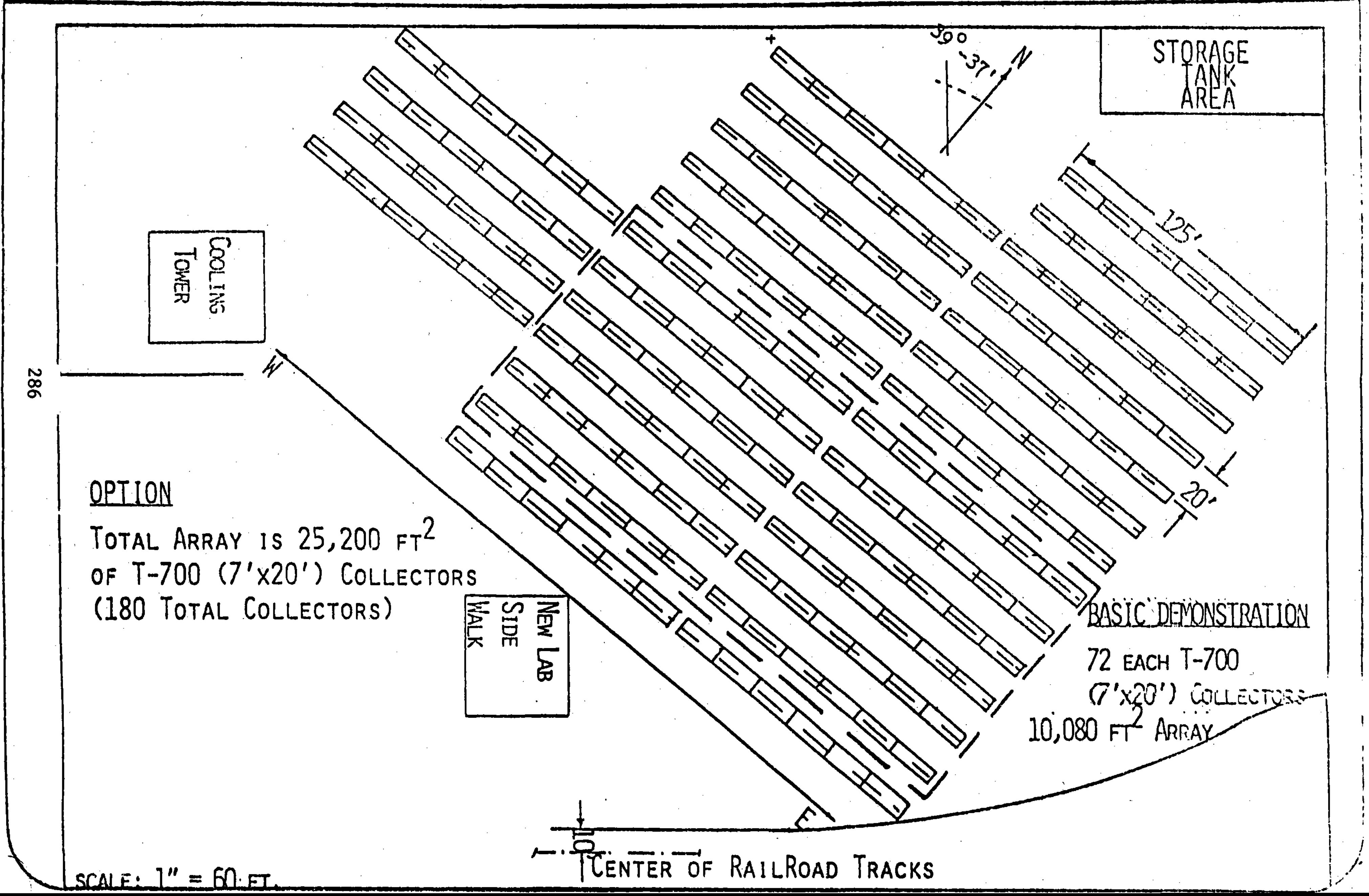
Southern Union Refining Company's Famariss Energy Refinery has worked diligently with Energetics Corporation in the conceptual and detail design for this unique application of solar generated steam. An area closely adjacent to the refinery and fronting New Mexico State Highway #18 has been designated for the solar collector array giving clear and unobstructed view to the passing public.

Space planned for the demonstration array is sufficiently large to handle an array of 25,200 square feet in size - an array more than twice the size of the 10,080 square feet proposed originally. Since the concensus of opinion at the October, 1978 Industrial Process Heat Work Conference was for a significantly larger demonstration program - up to 50,000 square feet in area- the option of increasing this demonstration from 10,080 square feet to 25,200 square feet was closely considered. Some actual provisions were incorporated into the detail design of the solar system to permit a rather straightforward increase in the demonstration array size, if the Department of Energy so chooses. In the system concept and detail design discussed in this volume, the idea presented during the initial conceptual design review (See Figure 1) for a 10,080 square foot array-expandable to 25,200 square feet-has been followed. Some minor changes were necessitated from the conceptual design because of availability of components and parts, refinements to the conceptual design encountered after the design review and for safety or environmental reasons.

A proposal covering Phase II effort and associated costs, required during Phase I, has been prepared and submitted in a separate volume.

It is hoped that the efforts of Energetics Corporation supplemented by Bridgers & Paxton Consulting Engineers and New Mexico Solar Energy Institute, is in line with the Department of Energy's wishes. The design of this unique application has been,highly rewarding to the participants.

SOLAR ARRAY



OPTION

TOTAL ARRAY IS 25,200 FT^2
OF T-700 (7'x20') COLLECTORS
(180 TOTAL COLLECTORS)

BASIC DEMONSTRATION

72 EACH T-700
(7'x20') COLLECTORS
10,080 FT^2 ARRAY

CONCEPTUAL DESIGN

Introduction

The final design for the Famariss Energy Refinery Solar System and its interface with the refinery is discussed in the following sections. The design follows closely that proposed in the Conceptual Design Review Report (dated 5 January 1979) with special emphasis given to equipment sizing and system operation. Further technical discussion, calculations, and detailed analysis can be found in the above reference.

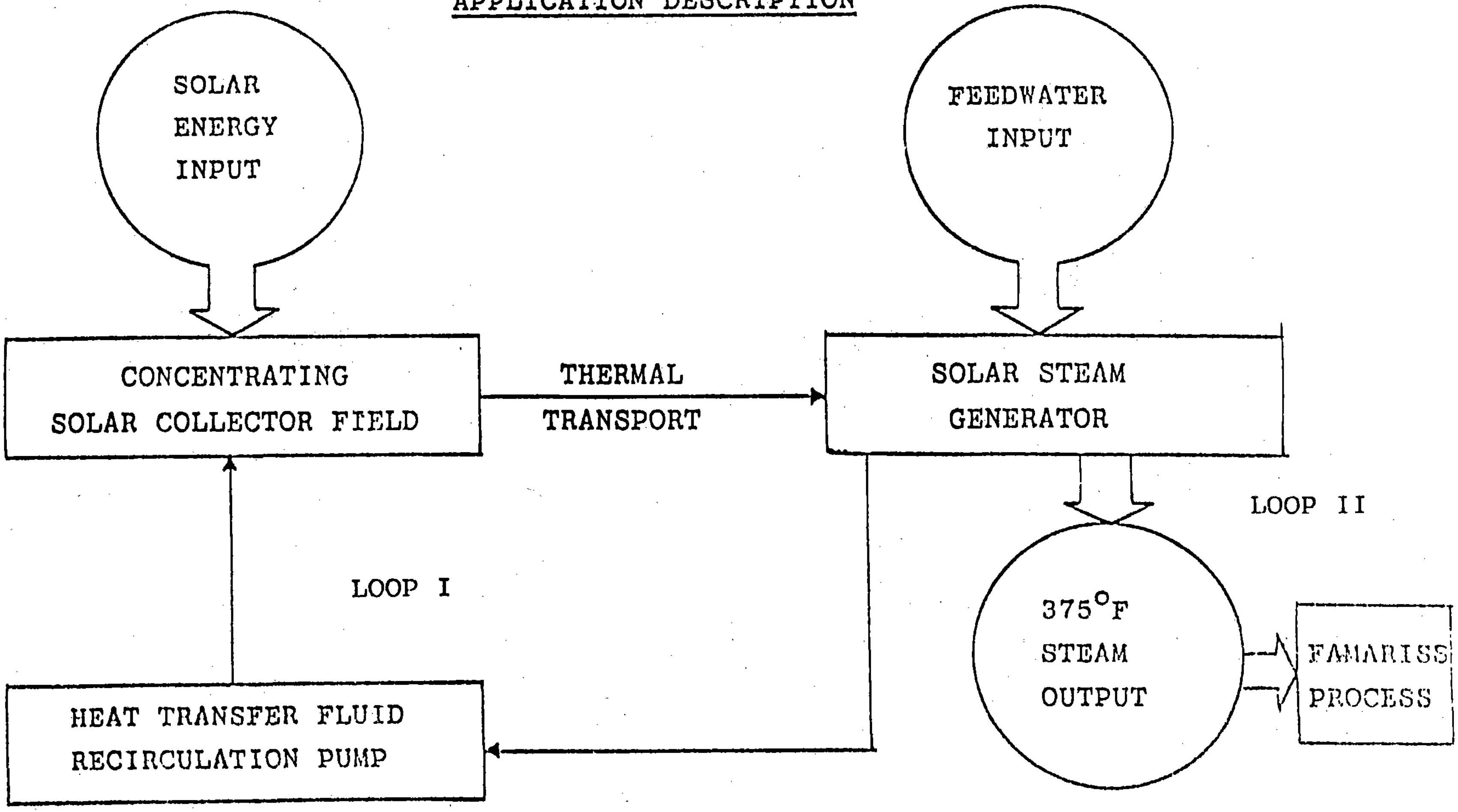
Solar System Design

The final solar system design utilizes a linear parabolic trough collector manufactured by Solar Kinetics, Inc. of Dallas, Texas. The system design incorporates 72 model T-700 collectors, each with aperture dimensions of 7 ft. wide by 20 ft. long, to provide 10,080 ft^2 of solar collector area. Six collector modules will be placed end to end to make collector arrays each with a separate tracking/drive unit. Thus, twelve arrays will make up the total solar field.

The solar process steam application at the Famariss Energy Refinery will be a two loop design. As represented in Figure 2 , Loop I will be the primary thermal transport loop where heat transfer oil (HTO) will be recirculated by a separate pump, through the solar collectors and solar steam generator (SSG). Loop II will be the interfacing loop between the Famariss Refinery

FIGURE 2

APPLICATION DESCRIPTION



and the solar system. It will incorporate feed water supplied by the refinery's boiler feed water pumps to the SSG. Also, steam discharged from the SSG back to the refinery's steam header pipe will be included in this loop. Feed water will be supplied at approximately 220°F while 175 psig dry saturated steam at 375°F will be provided to the Famariss plant.

The system schematic of the Famariss Refinery Solar Process Steam Application is shown in Figure 3 . Both Loop 1, the solar HTO thermal loop and Loop II, the SSG interface, are represented. The SSG essentially parallels the existing Famariss plant steam boilers. The refinery's steam system is composed of boiler feed pumps, deaerator, steam boilers, steam distribution piping, feed water piping (condensate return), and water treatment. The water treatment, in conjunction with the boiler blow down (not shown in Figure 3), controls corrosion and scaling in the boilers and steam system and is critical to continuous efficient operation. The various components of the solar system are the solar collectors, the HTO recirculation loop (piping), the HTO pump, expansion tank, SSG, blow down heat exchanger, and several control valves. These latter items are shown in the solar system flow diagram of Figure 4.

The HTO recirculation loop on the solar side of the process interface, Loop I, will be a constant flow system (except for system cold start up). Thus, only oil temperature in the collector field piping will vary in response to variations in the solar input. This will allow oil temperatures at a location

SYSTEM SCHEMATIC

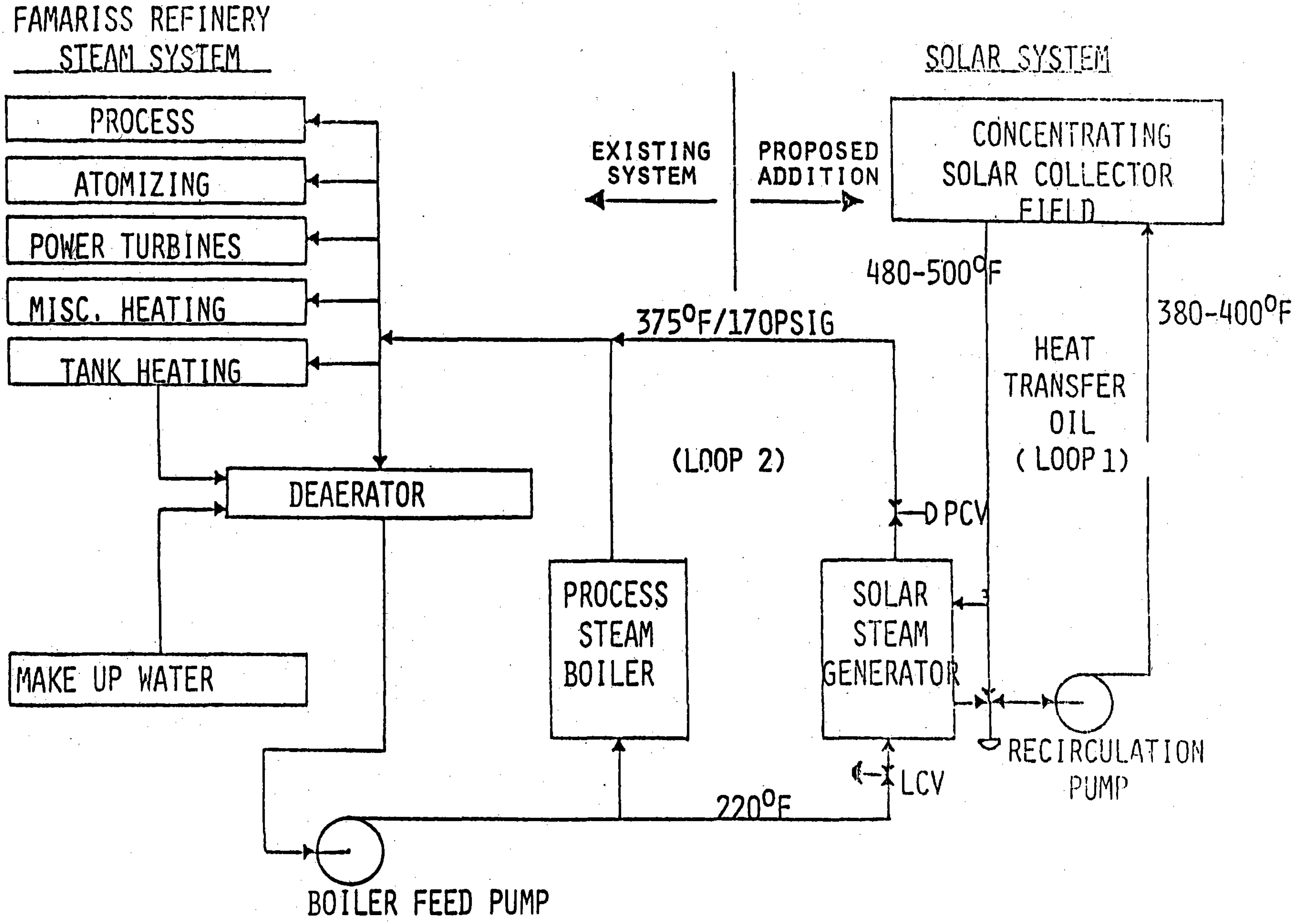


FIGURE 3

SOLAR SYSTEM FLOW DIAGRAM

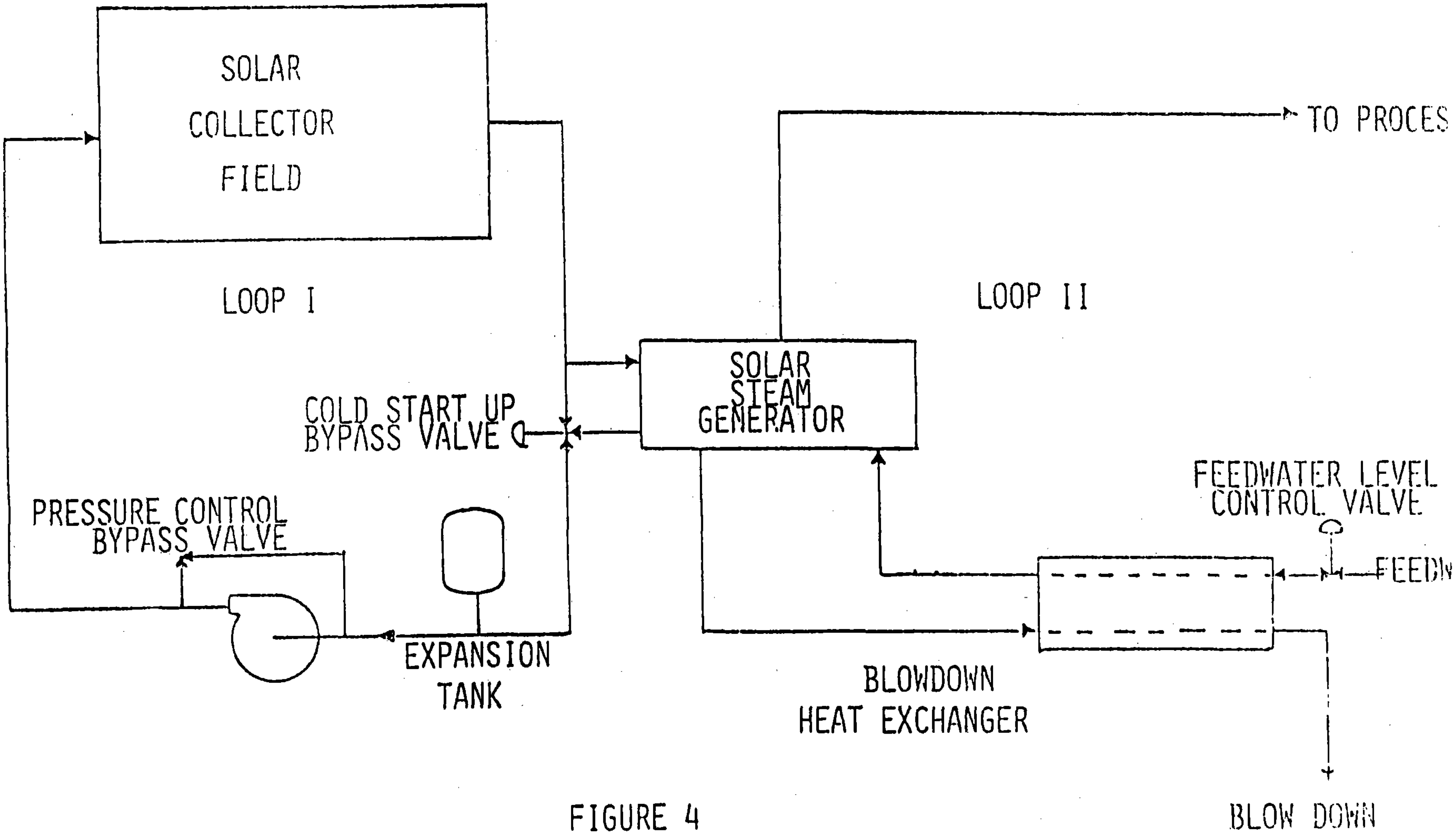


FIGURE 4

exit the collector field to operate throughout the day with temperatures of 500°F (the maximum collector design temperature) down to about 375°F (the saturated steam temperature in the SSG). The higher temperatures will correspond to the higher steam flow rates out of the SSG and to periods of higher solar insolation. At the SSG, the necessary internal water level will be maintained by a level control valve on the feed water inlet line. In addition, a specified blow down from the SSG (based on the refinery's water quality) will be provided to control scale and corrosion.

The SKI T-700 collector incorporates a reflective parabolic surface of FEK metallized acrylic film and a 1.5 inch outer diameter receiver tube coated with a black chrome selective surface. The receiver tube is surrounded by a Pyrex glass tube to minimize convection losses. The collector is rated for operation up to 250 psig and 500°F. Additional collector details are shown in the manufacturer's literature provided in the appendix.

The solar collector field configuration was arrived at after consideration of the process thermal energy requirement, piping thermal loss, and pumping power requirement. Both East-West and North-South collector row orientations were studied.As indicated in Figure 5 , the North-South oriented rows deliver approximately 8% more thermal energy on an annual basis but have extreme variations in energy output on a month to month basis (ie, 150% output in August vs 38% thermal output in December).

USABLE SOLAR ENERGY FOR THE
SOLAR PROCESS STEAM APPLICATION
AT THE FAMARISS ENERGY REFINERY

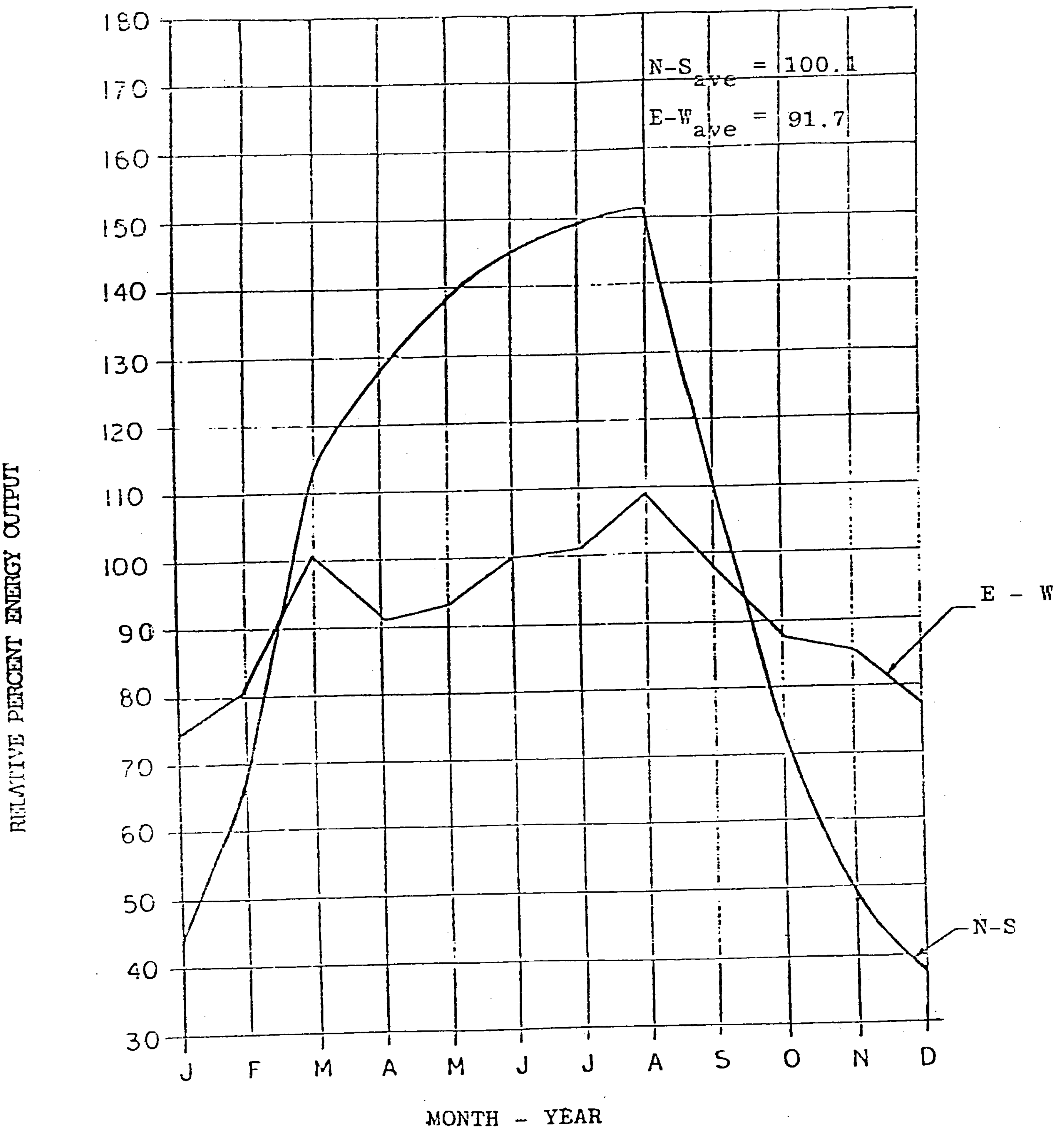


FIGURE 5

Comparatively, the thermal output from an East-West oriented collector field is much more consistent throughout the year with variation between only 75% and 109%. Thus, since the Famariss Refinery requires nearly 40% more thermal energy in the winter months than in the summer, the East-West field orientation was selected. Note that this decision would be much more important for a larger field size which supplied a larger percentage of the thermal energy requirements of the plant.

Based on the six collector module array (with a separate tracking/drive unit per array) several field configuration piping arrangements are possible. For the twelve array field (72 collectors) a configuration of either two, three, four, six, or twelve parallel flow loops would be possible. This number of flow loops would also equal the number of East-West collector rows and would contain 36,24,18,12,or 6 collectors in each row, respectively. As identified in the conceptual system design, the selected field configuration would directly effect the field piping thermal loss and pumping power. These items are summarized in Table 1 where the total system parasitic losses are listed for the possible East-West row configurations. For the design conditions specified, six East-West rows provide the minimum parasitic losses to the system. Twelve rows are nearly as effective as six but have the additional disadvantage of increased field piping cost (nearly twice the collector header piping length and cost as the six collector row manifold). It should be noted at this point that a field collector area of 25,000 ft^2

TABLE 1

SOLAR FIELD CONFIGURATION CRITERIA*

# E-W Rows or Flow Loops	Piping Thermal Loss, %	Pump Power Factor, %	Total Losses, %
2	0.1	13.2	13.3
3	0.2	3.9	4.1
4	0.3	1.6	1.9
6	0.5	0.5	1.0
12	1.1	0.1	1.2

* Based on percent of clear day energy collection at 425°F; 2" nominal pipe size with 3½" insulation thickness; 16' collector row to row spacing; 125 gpm HTO flow; 12 six-collector modules for 10,080 ft^2 aperture area.

would be configured by a similar analysis. Most probably, this field size would also be based on two arrays (twelve solar collectors) per individual flow loop. Because of the large increase in parasitic losses as the number of collectors per flow loop increase (or number of flow loops decrease, ie. Table 1), fewer than twelve collectors per flow loop would be considered. However, for this process application and these design conditions the twelve collectors per flow loop is the desired design basis.

Solar System Performance

Detailed solar system performance investigations indicate that the High Temperature Solar Process Steam Application at the Famariss Refinery will provide approximately 3.65 million pounds of steam to the refinery annually (based on 85% clear days). This is the energy equivalent of nearly 4.5 million cubic feet of natural gas for an operating boiler efficiency of 83%. The corresponding solar system annual efficiency is 41.8% (available solar insolation to net steam output) but all system parasitic losses reduce the net energy gain of the installation to 40.2% of the available solar insolation. A system performance summary is listed in Table 2. The peak collector thermal output will be about 2 million Btu/hr with a resulting steam flow from the SSG of 1880 pph. This results in a solar noon peak efficiency of 60.2% for insolation to steam output. Additional collector and system performance information is presented in Table 2.

TABLE 2

SOLAR SYSTEM PERFORMANCE SUMMARY

Peak Collector Thermal Output - 1.97 million Btu/hr (577 KW_t)

Peak System Steam Output - 1882 pph

Concentrator - Solar Kinetics, Inc T-700 Linear Parabolic Trough; 180° Rim Angle; 7 ft x 20 ft Aperture

Concentration Ratio - 16.4 (based on exposed receiver surface area)

Tracking - East-West Oriented Collector Field with Active Solar Elevation Tracking; Hydraulic Power Supply

Process Load - 375 F/175 psig Steam to Famariss Refinery (220 F feed water supplied to the SSG)

Collector Field Size - 10,080 ft^2 Total Aperture Area; 72 Collectors in 12 Arrays

Peak Efficiency - 60.2% (Insolation to net steam output)

Annual Efficiency - 41.8% (Insolation to net steam output)

Annual Fuel Savings - 4.27 Billion Btu*

---

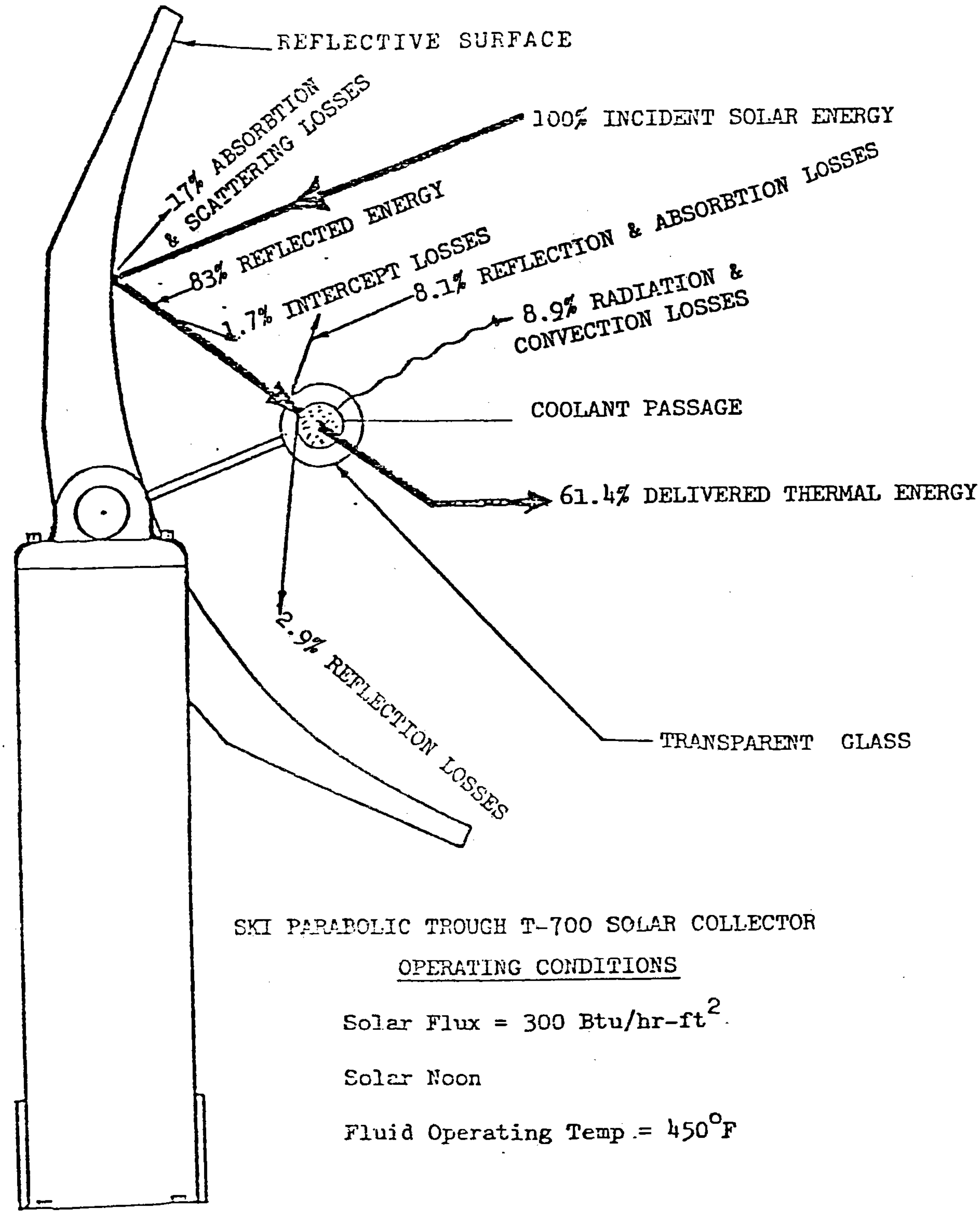
* Net savings after all system parasitic losses.

The instantaneous energy balance of the SKI T-700 solar collector is represented in Figure 6 . Approximately 61% of the incident solar insolation can be reflected, concentrated, absorbed, and transferred to the heat transfer fluid in the receiver.

The collector and solar steam generator full day performance is shown in Figure 7 where collector output and SSG output are plotted as function of solar time. The direct normal insolation (for a clear vernal equinoxial day) is also shown for comparison. As indicated, the collector daily thermal output is about 1298 Btu/ft^2 of collector aperture area with a corresponding day long efficiency of 43%. The collector peak output at solar noon (195 Btu/hr-ft^2) provides an instantaneous efficiency of over 62%. Based on steam generated, however, the corresponding day long and peak instantaneous efficiencies are 41.8% and 60.2% respectively. The reduction in performance is due to the system parasitic losses of HTO piping thermal losses and steam generator blow down thermal losses. All realistic system performance estimates must include such losses.

Of most importance for any solar system, however, is the annual system performance. This is shown in Figure 8 for the Famariss Refinery Solar Process Steam Application. The series of stepping blocks represent all subsystem and collector individual efficiencies with the overall system annual efficiency given in the final block. As indicated, the annual

INSTANTANEOUS ENERGY BALANCE



SKI PARABOLIC TROUGH T-700 SOLAR COLLECTOR

<u>OPERATING CONDITIONS</u>

Solar Flux = 300 Btu/hr-ft^2

Solar Noon

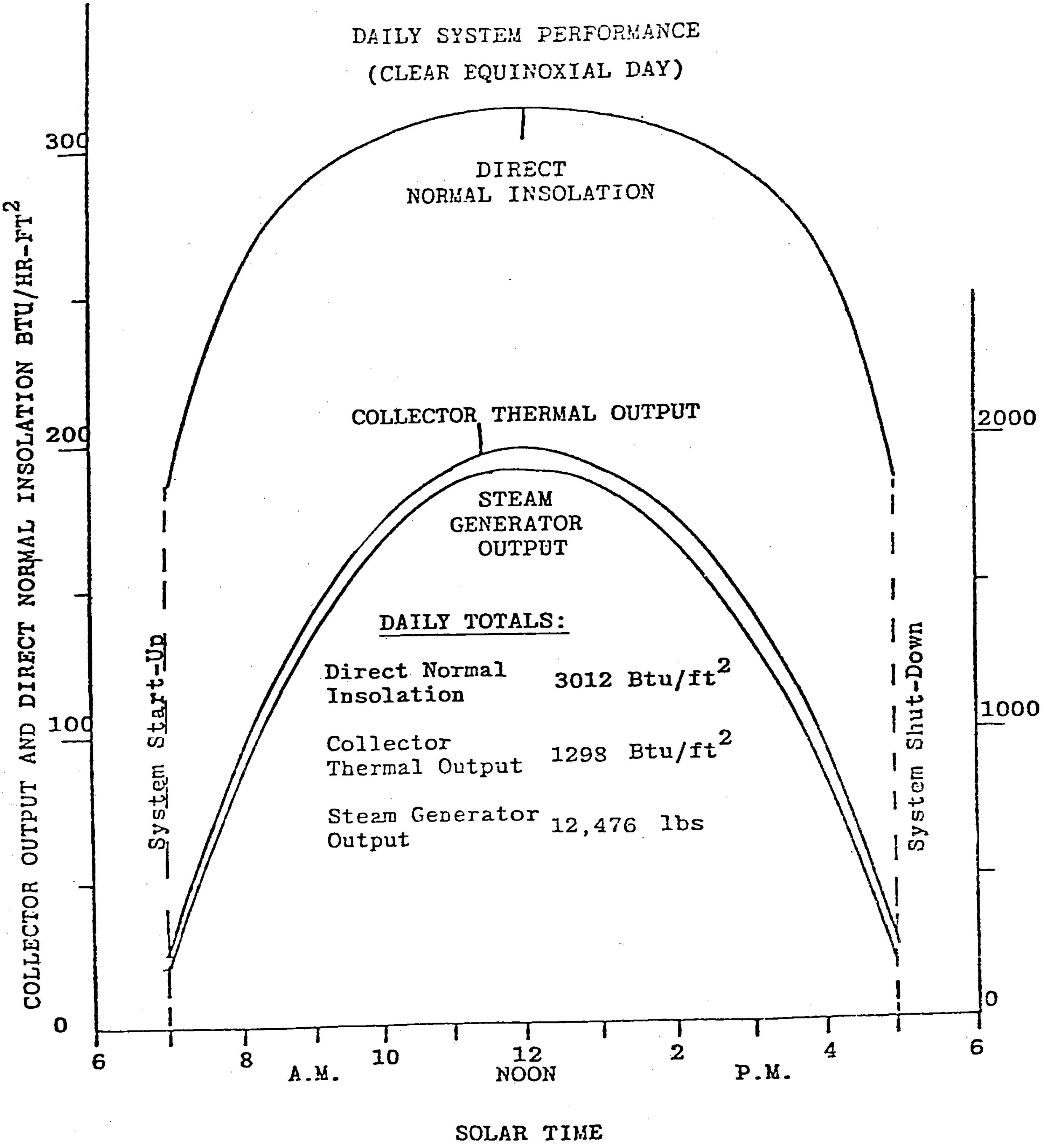
Fluid Operating Temp = 450°F

FIGURE 6

FIGURE 7

DAILY SYSTEM PERFORMANCE

(CLEAR EQUINOXIAL DAY)

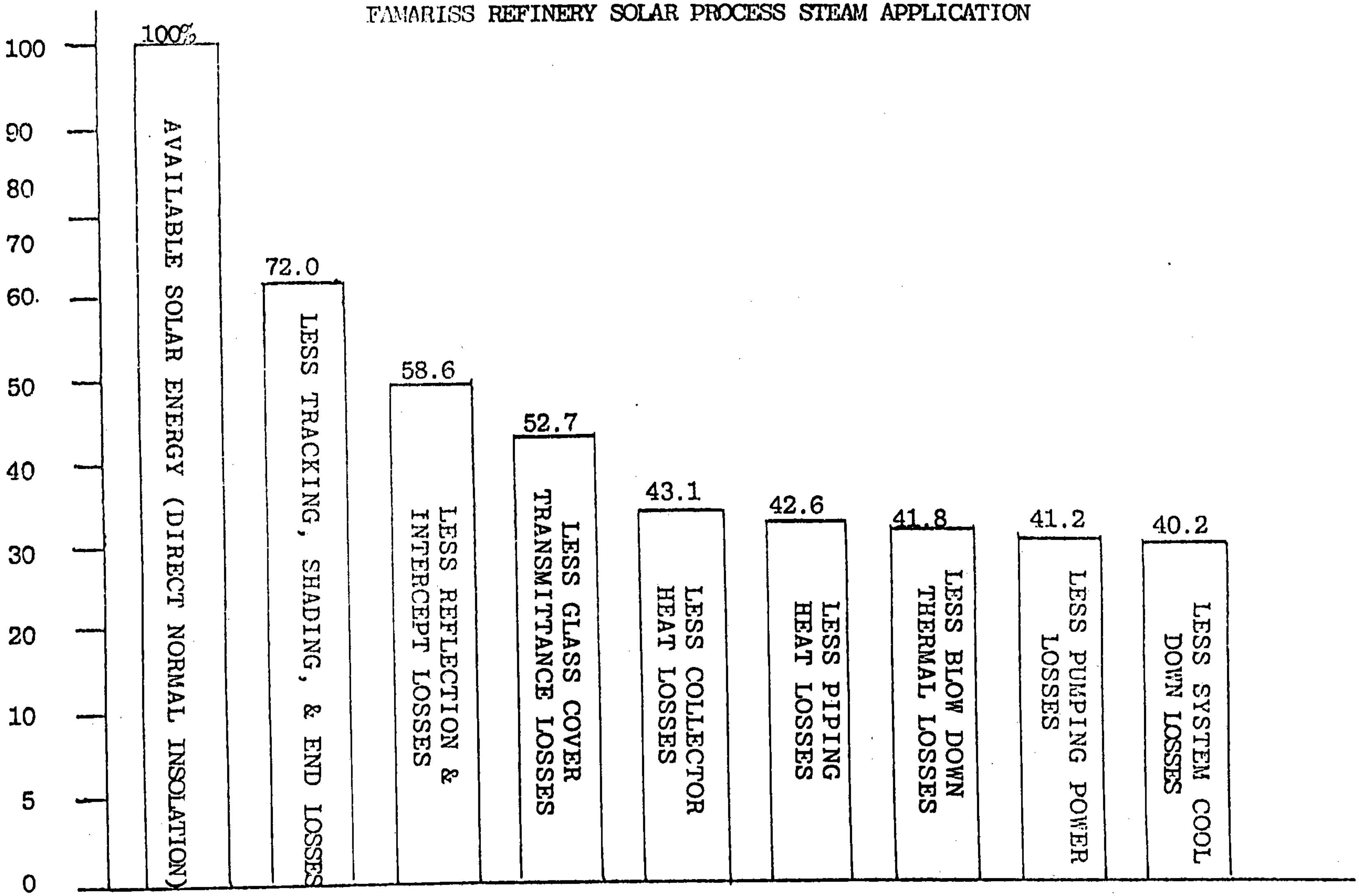


DAILY TOTALS:

Direct Normal Insolation	3012 Btu/ft^2
Collector Thermal Output	1298 Btu/ft^2
Steam Generator Output	12,476 lbs

FIGURE 8

ANNUAL SYSTEM PERFORMANCE
FAMARISS REFINERY SOLAR PROCESS STEAM APPLICATION



NOTE: 10,080 ft^2 SKI T-700 COLLECTOR ASHRAE SOLAR
DATA AVERAGE 27,500 PPH HTO CIRCULATION

system efficiency is 40.2%. The annual efficiency can also be expressed as the product of the individual subsystem or component efficiencies and factors. This breakdown in component efficiencies is represented in Table 3. Thus, nearly 40% of the available annual direct normal insolation can be utilized to reduce the conventional energy consumption of the Famariss Refinery after accounting for all system parasitic, operational, and shut down losses. Therefore, the annual performance of the 10,080 ft^2 installation with approximately 85% clear days would be to provide nearly 3.54 billion net Btu to the Famariss Refinery, thereby reducing fuel consumption for the generation of process steam by the equivalent of approximately 3.81 million cubic feet of natural gas or 23,788.81 gallons of fuel oil.

The individual component loss factors or efficiencies were determined by hour by hour system performance calculations for four selected days of the year, then averaged to obtain their estimated annual efficiencies. The solar data for the analysis was ASHRAE clear day insolation values for 32°N latitude. The representative four days used in the calculations were the summer and winter solstices and the vernal and autumnal equinoxes. The collector tracking, shading, and row end losses amount to an annual factor of about 0.720 (or 28% of the available insolation is not utilized). This factor is based on row to row spacing of sixteen feet and east-west row lengths of 120 feet (six collector modules). The cosine effect (tracking loss) is

TABLE 3

SOLAR SYSTEM ANNUAL LOSS FACTORS

Loss Category	Loss Factor	Product
Tracking	0.732	0.732
Shading (row to row)	0.994	0.728
Collector end loss	0.990	0.720
Reflection	0.830	0.600
Intercept	0.980	0.586
Glass cover transmittance	0.900	0.527
Collector heat loss	0.852	0.431
Field piping heat loss	0.988	0.426
Feed water piping heat loss	0.996	0.424
Blow down	0.986	0.418
Pumping power	0.985	0.412
Field piping cool down	0.990	0.408
Feed water piping cool down	0.990	0.404
Freeze protection	0.996	0.402

the largest loss in this factor with collector shading and row end losses amounting to only slightly over 1% of the available insolation (see Table 3).

The collector reflection and intercept losses are based on SKI literature values and provide a combined loss factor of about 0.813. Concentrator surface reflectivity of 83% was the primary loss in this factor with an additional 2% loss due to intercept losses.

The glass cover transmittance (90%) and receiver surface absorptivity (96%) are also based on SKI literature values, with their corresponding annual effects represented in Figure 8. It can be seen that after these optical losses, the annual collector optical efficiency should be about 52.7%. Thus, (based on the final system efficiency of 40.2%) only 12.5% of the available solar insolation is "lost" by the system in conversion from absorbed solar radiation to net energy savings to the refinery.

The collector thermal losses (included in the 12.5% annual system losses mentioned in the preceeding paragraph) amounts to approximately 7.5% of the available annual insolation. This results in a collector thermal loss factor of about 0.852 which indicates that nearly 15% of the absorbed solar energy is lost due to collector thermal losses while operating. It should be realized that these collector losses are not based on a constant collector fluid temperature, but on the variation in operating temperature caused by the constant flow system design. Note that the operating HTO temperature will nearly always remain between 375°F and 500°F however.

The field piping thermal loss factor was determined to be about 0.988 based on the pipe sizes and insulation thicknesses presented in the following section. Also, the same variation in operating fluid temperature as discussed for the collector thermal losses applies. The feed water piping heat loss factor, determined similarly, is 0.996.

The blow down thermal losses are an inherent loss for the Famariss Refinery Solar Process Application but is not necessarily indicative of all steam generation applications. This loss, caused by the deliberate release from the SSG of high temperature water, is required for system scale and corrosion control. Generally, this high temperature water is cooled down to near ambient temperatures by incoming boiler makeup feed water and would result in a negligible thermal loss to the system. However, the solar generator in the present system is about 800 feet from the inlet cold makeup water (to the existing steam boilers) and therefore can only exchange heat with the preheated incoming feedwater to the solar steam generator (which is about 220°F). This results in a blow down thermal loss factor of about 0.986 (when a continuous blow down of 10% of the mass of steam generated is maintained).

The pumping power loss factor was determined to be 0.985. This factor was based on a constant operational flow of 125 gpm of HTO through the collector field. The mechanical pumping energy was weighted by a factor of three in order to compare with the other system thermal parasitic losses. This weighting factor accounts for the actual thermal energy utilized in the thermodynamic conversion to work (or mechanical energy). The pressure drop through the collector field was based on removing the spiral ribbon (flow turbulence inducer) from the collector receiver.

The final system parasitic loss factors of approximately 0.98 and 0.996 account for the piping and collector thermal losses associated with cool down after system shut down and the energy required for freeze protection, respectively.Since the cool down losses occur every evening after a day of operation, they are repetitive and must be accounted for by preheating during morning start up. As indicated in Figure 8 these losses amount to less than 2% of the annual available solar energy. Energy required for freeze protection was determined from the annual degree days of heating required and the solar control building configuration.

Detailed Engineering Investigations for Conceptual Design

Several detailed engineering studies were completed in the process of finalizing the solar system design for this High Temperature Solar Process Steam Application. These studies included preliminary investigations of alternate concentrating collectors, all water solar system designs (no HTO loop), selection of the feed water supply concept and determination of system operation for freeze protection. Additional investigations completed were equipment cost/performance and sizing studies. These studies are individually discussed in the remainder of this section.

Alternate Collector Systems

In the conceptual design phase of this contract work, several concentrating collector designs were evaluated for application. Data on four commercially available collectors and one advanced design collector was obtained. All collectors were linear focus, single axis tracking, concentrating collectors with maximum operating temperatures of about 500°F. The collectors evaluated are shown in Table 4. In addition to the information of this Table, supplemental information on these collectors was obtained by visiting the Estancia Valley Solar Irrigation Project at Willard, New Mexico and Sandia Laboratory's Collector Test Facility in Albuquerque.

The Accurex and E-Systems collectors were not considered further due to their state of development. The E-Systems collector, while having a substantial improvement in whole day efficiency (due to a polar axis orientation), is not yet offered commercially. Accurex indicated they were modifying their present design to become more cost competitive but had no additional design information presently available.

The Solar Kinetics, Inc., Model T-700 (an improved version of the small Model T-500) parabolic trough was therefore

TABLE 4

CONCENTRATING SOLAR COLLECTOR COMPARISON DATA

Collector	Cost, $\$/ft^2$	Peak Eff @500 F, %	All Day Eff, %
Solar Kinetics, Inc Model T-500	19.25 (1)	49 (3)	30 (3)
Solar Kinetics, Inc Model T-700	19.25 (1)	58 (4)	39 (4)
Hexcel	19.00 (1)	58 (3)	36 (3)
Accurex	27.00 (2)	49 (4)	N.A.
Suntec "Slats"	22.00 (1)	47 (3)	N.A.
E-Systems, Inc Fresnel Lens	25.00 (2)	58 (4)	49 (4)

Notes:

(1) Manufacturers actual cost data Oct 1978.
(2) Manufacturers estimated cost data.
(3) Efficiency values obtained or calculated from: Dudley, V.E., and R.M. Workhoven, "Summary Report: Concentrating Solar Collector Test Results Collector Module Test Facility," Sandia Labs, May 1978.
(4) Manufacturers estimated performance data.
N.A. - Not Available

selected as the most cost effective collector for this application. It was anticipated that this "second generation" collector, already utilized in previous solar installations, would minimize system operational problems and provide higher system availability than unproven collectors (an important consideration for this solar process steam application). In addition, the larger aperture area per collector module would minimize field piping connections and cost. Finally, the unplanned but not insignificant fact that the headquarters of both Energetics Corporation and Solar Kinetics, Inc., are in Dallas, Texas contributed to the desirability of the SKI collector.

Collector Spacing and Shading

A detailed study was completed to determine the near optimum row to row spacing of the solar collector field. Based on the twelve collector East-West row length and an interconnecting 2 inch nominal pipe size (with 3½ inches of insulation), an energy loss for each collector row was determined as a function of the row to row spacing. The amount of energy lost annually due to collector shading and interconnect piping heat loss was calculated separately then summed to obtain an annual total quantity of energy lost. The annual shading calculations were based on hourly insolation values for the equinox and solstice days of the year. The piping heat loss was based on an average HTO temperature of 450°F and ten hour operational days. Both operating and overnight cool down thermal losses were accounted for. Results of this analysis are indicated in Figure 9. Although 25 feet row to row spacing provides nearly the minimum system energy loss (essentially zero shading loss), a cost/performance trade off indicates that based on a collector capital cost of \$50/million collected Btu (annually), or \$19.25 per ft^2 collector, the economic optimum spacing becomes approximately 16 feet (for installed interconnect piping and insulation costs of \$20 per linear foot). Thus, the 16 feet row to row spacing was utilized in the final design.

The energy lost due to shading was calcualted hourly by multiplying the available insolation (after tracking losses) by the fraction of aperture area shaded. The fraction of collector aperture area shaded was calculated from the following derived equation (for East-West linear tracking collectors on a horizontal plane):

$$\text{Fraction Shaded} = 1 - (D_s/W)\ \sin\{\tan^{-1}(\tan\{\text{BETA}\}/\cos\{\text{GAMMA}\})\}$$

where,

D_s = distance between adjacent parallel east-west rows
W = collector aperture width
BETA = solar altitude angle
GAMMA = solar azimuth angle measured from due south.

Piping and Insulation

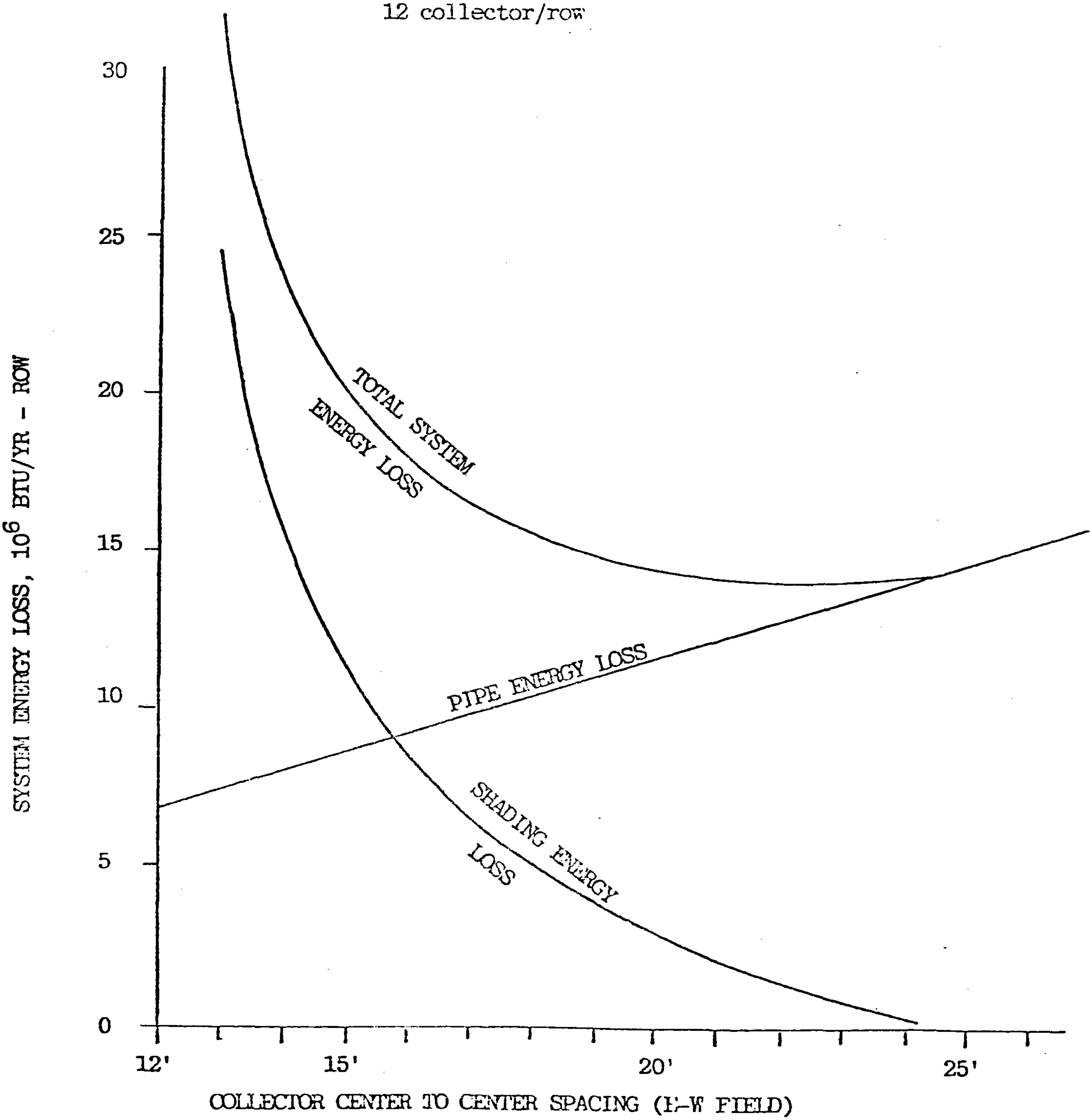
Detailed studies were also completed of the system pipe sizes. In addition to economic consideration, the feed water and steam lines were sized to allow expansion of the solar

FIGURE 9

COLLECTOR SYSTEM ENERGY LOSS vs

COLLECTOR SPACING

12 collector/row



collector field to 25,000 ft^2. Thus, no increase in these pipe sizes would be necessary for increasing the basic case collector area by up to 2½ times.

The feed water line was sized for minimum cost based on heat loss and fixed cost (capital recovery). However, the pipe size was so small (2 inch nominal pipe size selected) that the overriding factor for size selection was the allowance for field expansion to 25,000 ft^2. Pressure drop was not evaluated due to the current operation of high outlet pressure from the boiler feed pumps.

The steam and HTO piping sizes were determined by evaluating the costs due to operating pressure drop, fixed cost, and heat loss (based on a fixed insulation to pipe diameter ratio). In addition, the steam line size was further penalized for increased backpressure operation in the SSG (caused by reduced steam line sizes). Increased SSG operating pressures reduced the available log mean temperature difference (LMTD) by increasing the saturation temperature in the SSG and thereby requiring larger heat exchange surface areas to transfer equivalent quantities of heat. Based on the estimated price of \$25/ft^2 of heat transfer area (approximate quoted price), this penalty amounted to an additional capital expenditure of nearly \$100 per psi back pressure in the SSG (or steam line pressure drop). In all these line size evaluations, operating power to overcome pressure drop was converted to equivalent thermal energy (factor of three) for direct cost comparisons.

The cost of the thermal energy was based on the collected energy capital cost of $50 per million Btu per year ($19.25 per ft^2 collector area). The resulting pipe sizes of the steam and main oil lines were 2½ inch and 3 inch nominal pipe sizes, respectively.

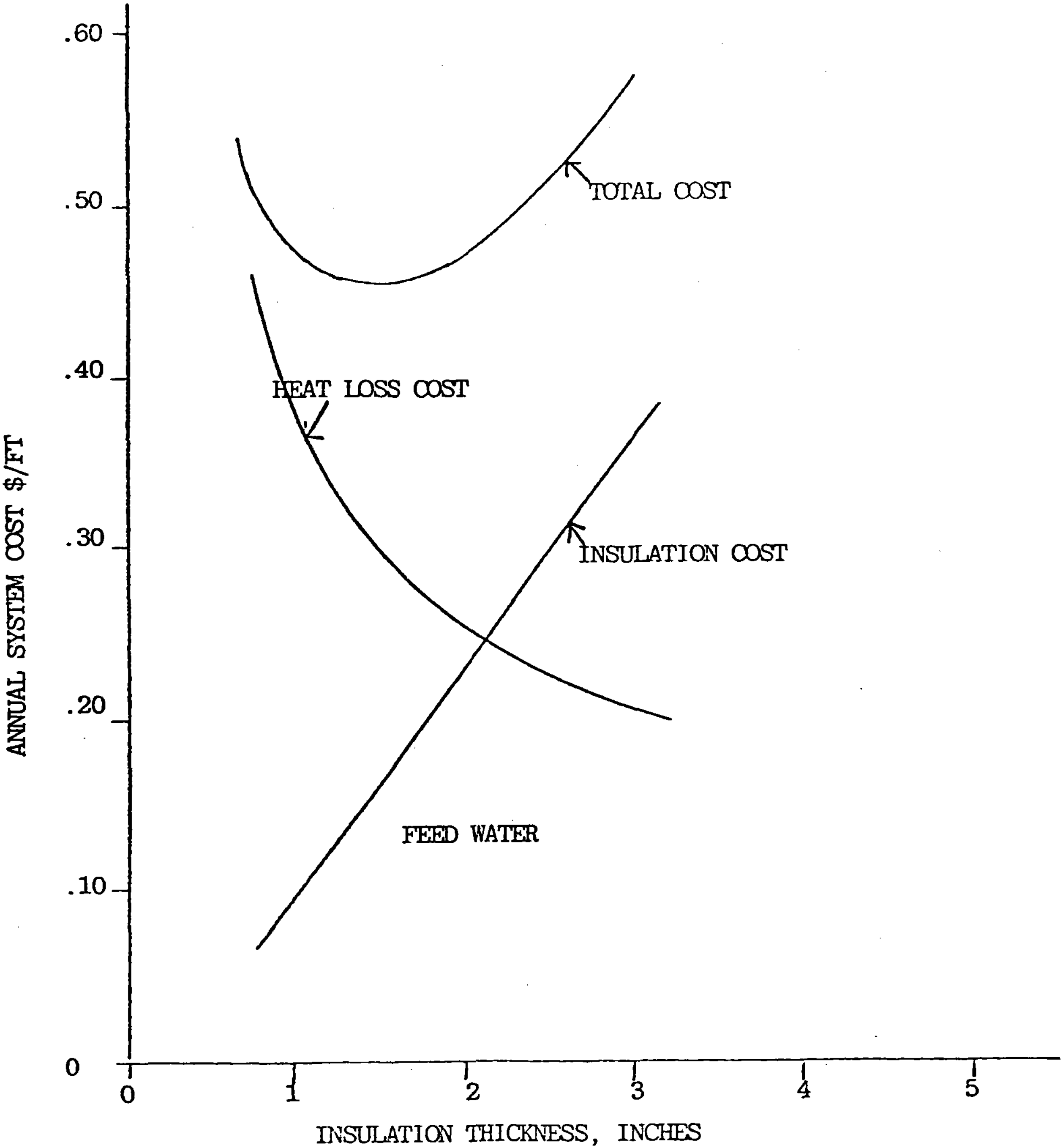
The economic optimum insulation thickness was determined similar to the pipe size, except that only the insulation cost and the cost of the heat loss were necessary for the analysis. The capital cost for annual collected insolation (the basis for economic comparison) was again $50 per million Btu. The insulation cost was the current price obtained from a national manufacturer. Heat loss was calculated for the actual pipe operating temperature and the annual heat loss was based on an operating time of 10 hours per day. Results for the feed water line are indicated in Figure 10 for a 12% capital recovery factor). The selected insulation thicknesses were 1½ inches, 3 inches, and 4 inches for the feed water, steam, and larger oil lines, respectively.

Pumps and the Solar Steam Generator

The HTO pump sizing was determined from considerations of parasitic power and heat exchanger LMTD. In addition, the final HTO flow was determined only after completion of the HTO economic pipe size study. Pumping power was based on total system hydraulic losses (collectors, distribution lines, control valves and SSG), pump and motor efficiencies of 0.92 and

FIGURE 10

ECONOMIC INSULATION THICKNESS*
METHODOLOGY



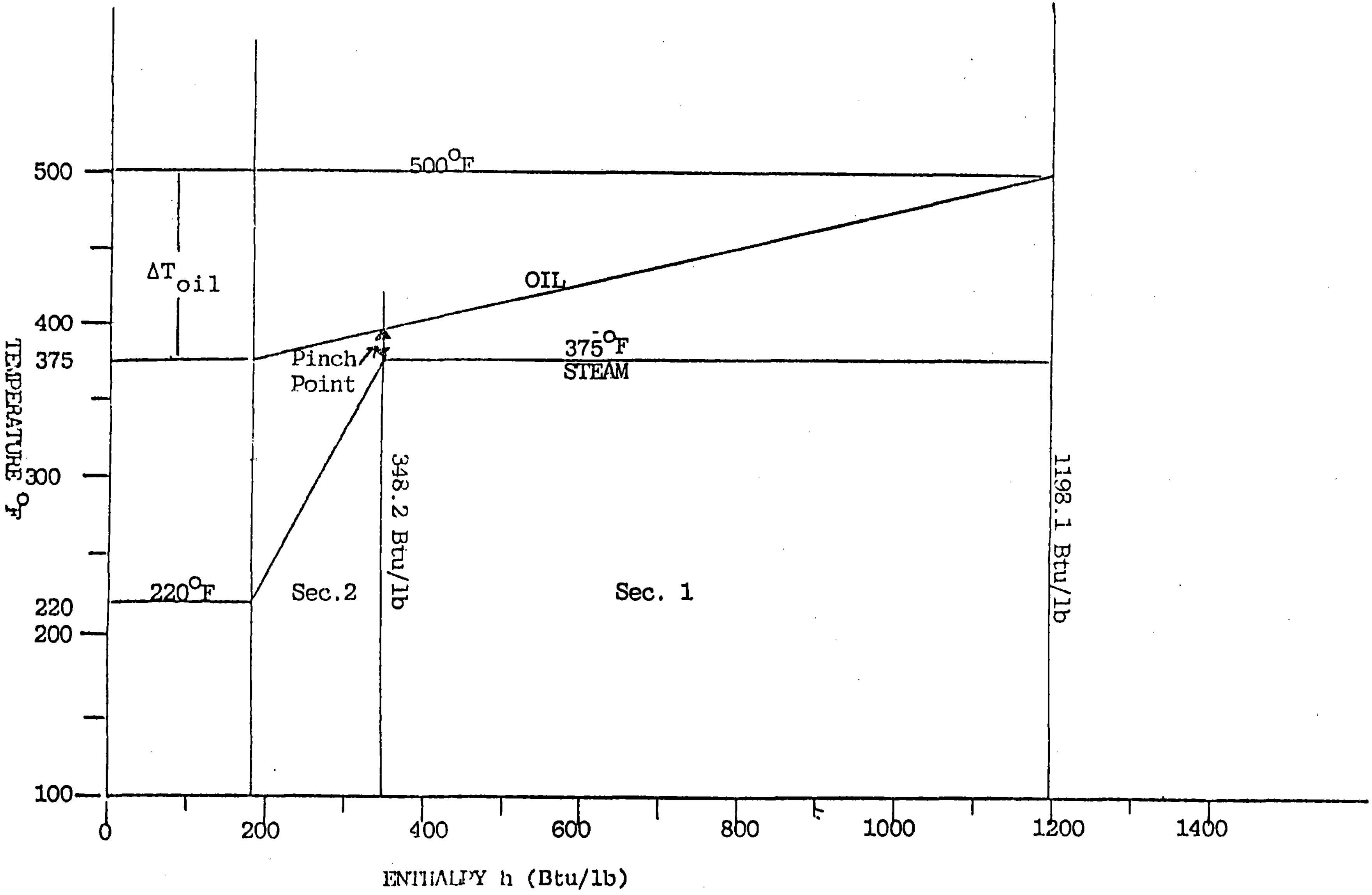
	OPTIMUM THICKNESS
1" Feedwater Pipe 220°F	1½"
2½" Steam Pipe 375°F	3"
2" Oil Pipe 500°F	3½"
3" oil Pipe 450°F	4"

0.55 respectively (with a factor of 3 used for conversion to equivalent thermal energy), HTO oil properties of Texatherm, and average 10 hour operational days. The SSG cost was determined to be approximately \$25/ft^2 heat exchange surface area while the capital cost of the annual collected insolation was again \$50/million Btu (constant for this collector and location).

A pictoral representation of what occurs in the SSG is given in Figure 11 where local operating temperature versus local steam enthalpy is represented along the heat exchanger surface area. As can be seen, the minimum HTO flow (at a 0^o pinch point) is possible only with an infinite size heat exchanger (after calculating surface area with the available LMTD). Conversly, for maximum LMTD (constant HTO oil temperature of 500^{o}F) the SSG has a minimum surface area, but requires an infinite HTO flow rate. Thus, the trade off becomes obvious. However, detailed studies of this relationship soon indicated that the minimum cost point required an abnormally large SSG (which no longer cost \$25/ft^2, but more) and was no longer of a practical design. Therefore, HTO flow was increased to a reasonable rate to further minimize the capital expenditure on this project. It is important to note that the design conditions must be met only at peak solar output conditions in order to prevent overheating in the HTO loop, but that the size optimization study was based on full day operation where the HTO oil temperature (along with the collector efficiency and SSG LMTD) varied hourly. These calculations, along with engineering judgements regarding

FIGURE 11

ENTHALPY vs TEMPERATURE FOR THE SOLAR STEAM GENERATOR



feasible SSG sizes, arrived at the design conditions of 125 gpm HTO flow and a SSG of nearly 600 ft^2 of heat transfer surface area.

The start up pump was sized on heat transfer considerations within the receiver tube. Design conditions selected were to provide a 1 ft/sec HTO velocity within the collector receiver tube at 32^oF. Heat transfer calculations indicated that the maximum oil film temperature would not exceed 350^oF under these conditions.

The conceptual design was also concerned with general design problems such as feed water supply to the SSG and required freeze protection operation. These items were decided on after economic and operational consideration, with special emphasis given to reliability and operability by the refinery personnel. Thus, feed water was selected to be provided direct from the refinery boiler feed pumps. This method utilized the existing water treatment facilities and minimized the number of pumps in the solar design. This concept did require about 800 ft of feed water pipe, however, to be connected from the boiler feed pumps to the proposed SSG. Freeze protection was considered for the water containing items (feed water pipe and SSG). It was decided to recirculate a small amount of hot water through the feed water line during freezing weather. Also, the SSG was decided to be kept in a building at 50^oF during the winter months. These combined freeze protection functions would amount to an energy loss of only 0.4% of the available annual insolation and is represented in Table 3 in the Solar System Performance section.

All Water System

An all water solar system feasibility study was completed during the conceptual design phase. This system involved replacing the HTO loop and the SSG with a water recirculation loop through the collectors and a steam separator. Two methods were considered for the all water design: 1) steam production in the collector field at 375°F and 175 psig; and 2) high pressure hot water production in the solar collector field at 406°F and 250 psig (the maximum collector pressure rating) with flashing across a throttle valve into the steam separator at 175 psig. Both methods had the major advantages of eliminating the HTO in the collector (with improved receiver tube heat transfer) and eliminating the costly solar steam generator. Although, the use of water within the solar collectors was not recommended by the collector manufacturer due to possible corrosion problems, it is felt that future generation collectors must consider this option due to the reduced system cost and complexity and the increased system performance (method 1 above could achieve up to 7% higher efficiency annually than the proposed HTO oil loop design). Additional considerations for all water designs are listed in Table 5.

Blow Down Heat Exchanger

The SSG blow down was investigated from a system performance view point where the necessity of a blow down heat exchanger was determined. The blow down heat exchanger transfers heat from

TABLE 5

COMPARISON OF ALL WATER AND HTO SYSTEM DESIGNS

Item	Benefit (compared to HTO design) Method 1	Method 2
Operating pressure drop	-	+
Flow imbalance	-	+
Pumping power	+	-
Operating temperature	+	+
Operating pressure	-	-
System performance	+	0
SSG cost	+	+
HTO cost	+	+
Corrosion problems	-	-
Fire hazard	+	+
Start up problems	+	+
Freeze problems	-	-
Cool down losses	-	-

-	indicates less desirable
+	indicates more desirable
0	indicates little or no difference

the hot water blow down from the SSG at 375^{O}F to the incoming feed water at 210^{O}F. Thus, a blow down heat exchanger reduces the discharged water temperature (and corresponding energy loss) from 375^{O}F to about 220^{O}F. With an ambient temperature of about 100^{O}F, it can be seen that the energy loss when using a blow down heat exchanger is more than cut in half when compared to operating with no blow down heat exchanger. In addition, as shown in Table 3 on the Solar System Annual Losses, the blow down annual energy loss can amount to approximately 1.4% of the total collected insolation even when using the blow down heat exchanger. Thus, without the blow down heat exchanger, energy losses could amount to nearly 3% of the total energy available-an entirely unacceptable amount. This heat exchanger thus provides an equivalent capital cost savings of nearly $3000 in collector area at minimal additional system cost.

It is important to note that the above blow down energy analysis is the "worst case" scenario in that the blow down is set at 10% of the steam flow from the SSG. While this value is presently that being used at the refinery boilers, the SSG is an unfired steam generator and is expected to require a lesser percentage blow down.

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR THE LONE STAR BREWERY

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ABSTRACT

This paper outlines the detailed design and system analysis of a solar industrial process steam system for the Lone Star Brewery. The industrial plant has an average natural gas usage of 12.7 MMcf per month. The majority of this energy goes to producing process steam of 125 psi and 353°F at about 50,000 lb/hr. Since the maximum steam production of the solar energy system is about 1700 lb/hr, the industrial process can accept all of the solar-produced steam.

The solar steam system will consist of 9450 ft^2 of Solar Kinetics T-700 collectors arranged in fifteen 90-ft long rows through which 67.5 gpm of Therminol T-55 is pumped. This hot Therminol then transfers the heat collected to a Patterson-Kelley Series 380 unfired steam boiler. The solar-produced steam is then metered to the industrial process via a standard check valve.

OBJECTIVE OF PROJECT

The objective of this research and development project is to design, construct, and operate a demonstration system to interface a solar energy conversion system with the present industrial steam process at the Lone Star Brewing Co. This solar energy system will apply solar state-of-the-art components and technology to the industrial process to determine the technical and economic feasibility of producing low pressure steam.

The current status of the project is that the final design has been completed and the construction activity has been initiated. The recent accomplishments are, therefore, the activities required to complete the final system design and system analyses. Since the construction phase has not yet started, no significant problems have been encountered, but this activity will be substantially underway during the next six months.

INDUSTRIAL PROCESS STEAM SYSTEM

Lone Star Brewery has a steam requirement of 125 psi and 353°F at approximately 50,000 lb/hr. This steam is manufactured by two 30,000 lb/hr steel shell-and-tube Keystone Boilers with heating surfaces of 3582 ft^2 and a maximum allowable working pressure of 200 psi. These boilers are fired by natural gas with diesel fuel burners installed for use as a supplement in the event of a natural gas curtailment. In addition to the Keystone Boilers, Lone Star also has a 50,000 lb/hr Erie City I.W.I. boiler with a heating surface of 4666 ft^2 and a water wall heating surface of 598 ft^2 that has a maximum allowable working pressure of 160 psi and is fired by natural gas. This boiler is also outfitted with two combination gas and oil burners which have a rating of 30,000 lb/hr. The steam pressure is controlled to a constant 125 psi, 24 hours per day. The maximum steam load is 60,000 lb/hr during the work day with 40,000 lb/hr at night. During the weekend the load is a constant 6000 lb/hr.

SOLAR SYSTEM INTERFACE

Steam is presently generated by three boilers, each producing steam at a gage pressure of 125 psi and a temperature of 353°F. Boilers deliver steam to a common header which feeds the various steam loads. Interface of the solar system with the existing process is to be accomplished by injecting the solar-produced steam into the main steam header that passes through the canning warehouse just below the collector field, thereby minimizing the piping runs between the collector field and boiler, and between the boiler and steam header. The piping which carries this steam will be connected to the plant steam header via a check valve and a gate valve provided in the solar steam line just before its point of connection to the header. The check valve in the solar steam line will serve to prevent plant-produced steam from flowing upstream in the solar line while solar steam is not being produced but, yet, will admit solar-produced steam to the plant header when it is available at the plant pressure of 125 psi. The gate valve in the solar steam line will allow positive manual shutoff of the solar line at any time for required maintenance or adjustment of the system. Interface being accomplished in this manner will allow all of the solar steam to be utilized in the plant processes and will diminish the loads on the existing boilers since their controls are such as to automatically limit their firing to produce a constant pressure at the steam header.

CONCEPTUAL DESIGN

The conceptual design for this system is by choice a very simple one. We have striven to minimize operation and maintenance problems while, at the same time, providing a workable and economical system. The design concept is to pump a heat transfer fluid through a collector field and then pass this heated fluid through the tube bundle of an unfired steam boiler. The steam produced in the shell of this boiler is then transported to the process steam header under the developed pressure and metered to this header by a standard check valve. Feedwater from the process deaerator, which is fed to the existing boilers by three boiler feed pumps in parallel to a common header, will be tapped for make-up to the solar-fired boiler.

An optimization study was conducted to determine the most cost-effective configuration of the system as well as the optimum size of each system component. The results of this study are shown in Figure 1. This figure indicates that a collector field configuration of fifteen 90-ft long rows spaced on 13 ft 4 in. centers is the optimum, giving a field size of 9450 ft^2. The collector field flow rate is 67 gpm with a pump head of 50 psi. The collector loop piping is 2-in. welded black steel pipe with 2-in. fiber glass insulation. The temperatures shown in Figure 1 are for ideal conditions of 285 Btu/hr-ft^2 and an ambient temperature of 95°F. The calculated collector inlet temperature is 365°F, and the collector outlet temperature is 475°F. These temperatures give an average collector fluid temperature of 420°F. At these temperatures, the maximum steam flow rate is 1683 lbs/hr, and the maximum energy transfer to produce this amount of steam plus heat the condensate from 200°F to the steam temperature of 353°F is 1.7 x 10^6 Btu/hr. The yearly system output, therefore, is 3192 x 10^6 Btu or 3.050 x 10^6 lbs of steam.

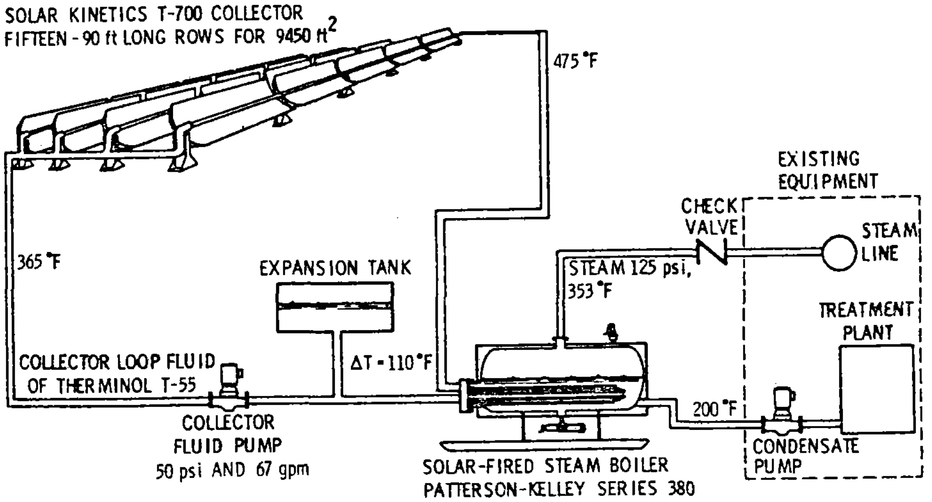

FIGURE 1. SCHEMATIC OF CONCEPTUAL SOLAR SYSTEM DESIGN

SYSTEM PERFORMANCE

The predicted system performance at peak ambient conditions is a collector thermal efficience of 63%, and a maximum energy transfer of 1.7 x 10^6 Btu/hr. This collector output will provide enough energy to heat the boiler feed condensate from 200°F to 353°F and produce 1683 lbs/hr at this peak condition. The predicted yearly performance is shown in Table I.

CONCLUSION

The system designed during the initial phase of this project was by choice a very simple one. A heat transfer fluid will be pumped through a solar thermal collector field, heated up, and then passed through a standard industrial unfired steam boiler. When the steam pressure in this vessel exceeds the pressure existing in the main plant steam header, solar-produced steam will be injected, which will have the same effect on the existing steam generation system as a reduced load. In this way, no storage system or sophisticated control system

TABLE XV. SYSTEM PERFORMANCE FOR AN AVERAGE YEAR

Month	lbstm, 10^3 lbs/month	QC, 10^6 Btu/month	QP 10^6 Btu/month	HSOL, Btu/day ft^2	ISOL, Btu/day ft^2
Jan	142.3	150.2	5.5	915	1290
Feb	147.4	154.7	4.4	1103	1225
Mar	204.9	214.0	5.0	1523	1414
Apr	211.5	220.5	4.8	1676	1406
May	235.8	245.6	5.2	1725	1563
Jun	340.1	354.1	7.5	2030	2096
July	382.9	398.5	8.2	2084	2332
Aug	359.5	374.5	8.0	1892	2365
Sep	314.8	328.8	7.7	1678	2269
Oct	257.1	268.5	6.3	1452	1850
Nov	179.3	188.4	5.6	1070	1527
Dec	140.1	148.1	5.4	875	1350
Yearly	2915.7	3045.9	73.6	1504	1714

is required. This design also provides a safe, reliable, and minimal maintenance system.

As with any other prototype system, this initial system cannot be justified on a purely economic basis. It has been estimated, however, that with the experience and knowledge gained from this installation, along with the projected decrease in collector cost due to mass production and increase in conventional energy cost, a cost-effective system can be designed and built within the next six years without any change in government incentives. This period can be shortened if this mass-produced level of collectors can be reached earlier or if appropriate incentives are increased, such as larger investment tax credits or accelerated depreciation allowances.

One of the key features of this system design is the incorporation of a solar steam system in a conventional industrial location. Most industry is located in large urban centers where the value of land is at a premium and the installation of systems must be considered for roof mounting. The current cost of mounting these systems on existing roof tops appears to be disproprotionally high due to the unknown wind loads imposed by a large number of collector rows. Single collector row wind tunnel studies have been conducted and peak wind load conditions have been determined, but the blockage effect of multiple collector rows has not been determined. It is expected that this blockage effect will be substantial. The roof support structure must, therefore, be designed on the worst-case stand-alone condition, or be designed so that the lifting force of one row will be counteracted by the downward force of the next row. The system designed for this project will include a data acquisition system to accurately measure these wind loads of multiple rows so that the building roof modifications in the future do not need to be as overdesigned as they now are. It is also projected that if new industrial construction is designed with these types of systems in mind, then the cost of providing roof support system will be as economical as current proposed ground-mounted systems if the value of land is considered.

The other key feature of this design is the unmatched visibility afforded to both the general public and the industrial community. A tour of this facility will be avilable with no prior arrangements from 10:00 a.m. to 5:00 p.m., Monday through Friday, 12 months per year. Since San Antonio, Texas, is one of the country's ten largest cities with a large modern airport providing nonstop service from most of the country's large metropolitan areas, plant engineers from all over the country can fly in, tour the facility, and return the same day or, at worst, stay over one evening. The drive from the municipal airport to the Lone Star Brewery is less than 30 minutes on San Antonio's new modern expressway system. In addition to the ease of making a special plant visit, the Brewery annually receives over 400,000 visitors to tour their present facility. Since SwRI numbers 300 of the nation's largest industries on its current client list, industry representatives that regularly visit the Institute for the solution of a variety of technical problems can very easily tour the solar steam system because both SwRI and the Lone Star Brewery are located in the same city.

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR STAUFFER CHEMICAL COMPANY

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ABSTRACT

A solar steam-generation facility has been designed for Stauffer Chemical's Henderson, Nevada production complex under the auspices of DOE's Industrial Process Heat Program (contract EM-78-C-03-1882). The design features a 984 m^2 (10,592 ft^2) array of line-focusing parabolic collectors which directly heats pressurized water. Saturated steam at 187°C (368°F) and 1170 kPa (170 psia) is produced by means of a flash separation step. A peak steam flow rate of 900 kg/hr (2000 lbm/hr) is expected, with annual production totaling 1.5×10^6 kg (3.4×10^6 lbm).

PROGRAM OBJECTIVES AND STATUS

This work is being sponsored by the U. S. Department of Energy to demonstrate the feasibility of using solar energy for industrial steam production in the 300-550°F temperature range. The program guidelines encourage project participants to work within the constraints of state-of-the-art solar technology, developing benchmark engineering design criteria, operational experience, and a realistic understanding of system economics. As a prerequisite, industrial participants are expected to have an established reputation for aggressive energy conservation activities.

Stauffer Chemical Company, headquartered in Westport, Connecticut, was selected as one of the program's prime contractors. Working through its design subcontractors, Stauffer has produced a detailed design for a direct-heating, pressurized-water steam-generation system. An artists's conception of the facility is shown in Figure 1. At this writing, Phase I (the analysis and design of the system) has been completed. A funding decision for Phases II and III (construction and system monitoring, respectively) is pending.

THE SITE AND PROCESS DESCRIPTION

The system is to be installed at the Stauffer Industrial Chemical Division Plant located in Henderson, Nevada. Henderson is located approximately 20 miles southeast of Las Vegas, in a climatological region especially noted for its solar potential [1]. The plant primarily produces chlorine (Cl_2) and caustic soda (NaOH) through the electrolysis of $NaCl_2$ and complementary chemical stripping processes. The stripping processes--common to manufacturers of chlorinated solvents, paper products, and hydrocarbons--utilize steam to recover important chemical intermediates, and represent the principal end-use for the solar-generated steam.

Because of the enormous size of the plant and the process, the 984 m^2 collector array will provide less than 2% of the peak steam flow requirements of the plant. This relatively low load fraction is of minor consequence in that the magnitude of the solar project is sufficient to enjoy internal economies of scale. Further, the relative size of the load obviates the need for thermal storage in the solar system--a fact which simplifies system design and is likely to be encountered in many other industrial solar energy applications.

KEY DESIGN CONSIDERATIONS

The rationale for the system's thermodynamic configuration is fully described in Reference 2. As indicated in the simplified schematic appearing in Figure 2, a direct, pressurized-water heating cycle has been chosen. It is felt that this type of cycle offers the simplicity and cost-effectiveness prerequisite for widespread acceptance of medium- and high-temperature solar IPH technologies.

Design efforts also concentrated heavily on the control of the system's parasitic power requirements, particularly those attributable to the main circulation pump (see Ref. 3). Two complementary approaches were chosen. The first involves the use of an elevated flash tank which, because of hydrostatic effects, provides a portion of the pressurization required to prevent boiling in the collector receiver tubes. Normally, this pressurization would be totally supplied by the pump. The second approach involves a speed-control system for the pump. The pump speed follows an operational path which optimizes pump horsepower as a function of insolation.

The design also addressed problems which are likely to be encountered in many industrial environments. For example, materials studies undertaken during the design effort pinpointed potentially serious questions as to the viability of aluminized mylar reflector surfaces employed in many line concentrators. Initial data [3] suggest serious optical degradation may occur in a relatively short time. Consequently, the mechanical specifications call for a sagged-glass reflector material with back-silvering. It is expected that this material will be significantly more compatible with the industrial environment, while having equal or better optical properties than the aluminized mylar.

Overall, the mechanical and structural design attempted to streamline fabrication and installation procedures. The designers were fortunate to have access to the documented experience, both positive and negative, of earlier IPH projects as a guide. The design has a modular flavor for easy expansion and/or replication.

SYSTEM DESCRIPTION

The major system components include the collector array, an elevated steam-separation drum, a high-pressure piping network, and an industrial-grade, microprocessor-based control system. The thermodynamic cycle employs a single working fluid (water) and is designed so as to maintain subcooled liquid conditions in the collector receiver tubes at all times. No significant thermal storage is included in the system. Makeup water is supplied from the main plant's boiler feedwater supply system.

Figure 3 presents a detailed mechanical schematic. The collectors are configured in 16 distinct, continuous, north-south rows which are progressively manifolded to single inlet and outlet pipes. The collectors are of the linear parabolic type, as manufactured by Suntec Systems, Inc. The single-axis tracking modules feature a sagged-glass reflector surface. The outlet of the collector array is connected to a manually set flash valve, connected in turn to the upcomer section of the steam-separation drum. The drum is an ASME pressure vessel with a volumetric capacity of 1100 liters (300 gallons). To provide a positive pump suction head, the tank is elevated some 6 meters (20 feet) above the level of the receiver tubes. The elevated tank also provides a means by which to reduce parasitic power requirements (see Ref. 3).

Saturated or subcooled liquid is removed from the tank via a downcomer section. Valve AV-1 controls makeup to the system, operating in response to the liquid level in the steam drum. The resulting mixture is directed to the inlet of a single-stage centrifugal pump, P1, which features an electronic, variable-speed drive. The outlet of the pump is connected to the return manifold of the collector array, completing the liquid circulation loop.

Steam, when available from the steam drum, is removed via a 3" line whose outlet is positioned in the tank's vapor space. Back-pressure control valve PCV-2 modulates flow so as to maintain the design operating pressure (hence temperature, under saturated conditions) in the tank. The outlet of PCV-2 is connected to the plant's steam-distribution system.

An industrial-grade, microprocessor-based controller oversees system operation. The controller is programmed to follow a path which minimizes pumping horsepower by controlling pump speed as a function of operational conditions. Freeze protection is achieved by a pump recirculation scheme backed by an emergency, manual, drain-down operation.

The maximum collector flow rate is on the order of 530 liters/min (140 gpm) at a total design head of 640 kPa (93 psi). The corresponding peak horsepower is 8.2 kw (11 hp). Due to pump-speed reductions at off-peak insolation levels, the annual parasitic pumping power has been appreciably reduced.

PERFORMANCE MODELING

The transient thermal performance of the system was simulated under the TRNSYS computational framework [4]. Ten special subroutines were developed to chart time-dependent mass and energy flows for the system components. Details of the simulation effort appear in References 3 and 5.

System-performance projections were based on the characteristics of the standard Suntec collector equipped with an aluminized mylar reflector surface. An annual steam production of 1.5×10^6 kg (3.4×10^6 lbm) was predicted. Steam production may be enhanced by the use of sagged-glass reflector surfaces, but actual test data were not available at the time of this writing. The annual pumping power has been computed to be 1.3×10^4 kw-hr (1.8×10^4 hp-hr).

PROJECT COSTS AND ECONOMICS

Preliminary cost estimates suggest that the system can be constructed at a total cost of $755,000, including a portion of the on-site construction management fees. This figure corresponds to a unit cost of $767.28/m^2 ($71.28/ft^2). Based on the predicted annual steam production, each square foot of collector will yield $1.08 in savings during the first year of operation. The savings were computed assuming natural gas as the displaced fuel and that the gas is available at $0.27/therm. These data yield a very crude "payback period" of 66 years.

The capital budgeting question is more appropriately addressed in terms of a discounted cash flow analysis. Such exercises are highly sensitive to the assumed price escalation scenarios for the displaced fuel, preferred discount rates, the corporate tax rate, plant depreciation schedules, and the impact of investment and energy tax credits. While these effects are comprehensively treated in Ref. 3, typical calculations--accounting for the effects of a 50% corporate income tax rate and the current 20% combined federal investment and energy tax credit--consistently yield system payback periods in excess of 20 years. Impending revisions to the Federal Tax codes, increasing fuel cost pressures, and further reductions in IPH system costs are likely to improve this economic picture in the near future.

PROJECT PRINCIPALS

The prime contractor's representative is Mr. George Stewart, Plant Manager of Stauffer's Henderson, Nevada, facility (702-565-8781). Project management and structural engineering efforts have been coordinated by Mr. Ira S. Rackley of Chilton Engineering, Sparks, Nevada (702-331-2277). Mr. Jerry O. Bradley of the Desert Research Institute, Boulder City, Nevada (702-293-4217) managed the design of the data-acquisition system and economic modeling. Dr. Harry T. Whitehouse directed the efforts at Pacific Sun Incorporated of Palo Alto, California (415-328-4588). Pacific Sun was responsible for the mechanical design, thermal/hydraulic analysis, and computer-simulation efforts.

ACKNOWLEDGMENTS

The design team would like to express their appreciation to the personnel of the USDOE, SERI, Lawrence-Berkeley Laboratories, and Sandia Laboratories for their continued technical and programmatic support.

REFERENCES

1. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, Intertechnology/Solar Corporation Report, COO/2829-1, Watertown, VA, 1977.

2. Phase I Conceptual Design Report, "Solar Production of Industrial Process Steam--Stauffer Chemical Company" (DOE Contract EM-78-C-03-1882), January, 1979.

3. Phase I Final Design Report, "Solar Production of Industrial Process Steam--Stauffer Chemical Company" (DOE Contract EM-78-C-03-1882), October, 1979.

4. Klein, C. A., et al., "TRNSYS: A Transient Simulation Program," Report 38-10, University of Wisconsin's Solar Energy Laboratory, June, 1979.

5. Whitehouse, H. T., and Ortiz, P., "Transient Simulation of a Solar, Flash-Separation Steam-Generation Cycle," Proceedings, System Simulation and Economic Analysis Conference, San Diego, CA, January, 1980 (in preparation).

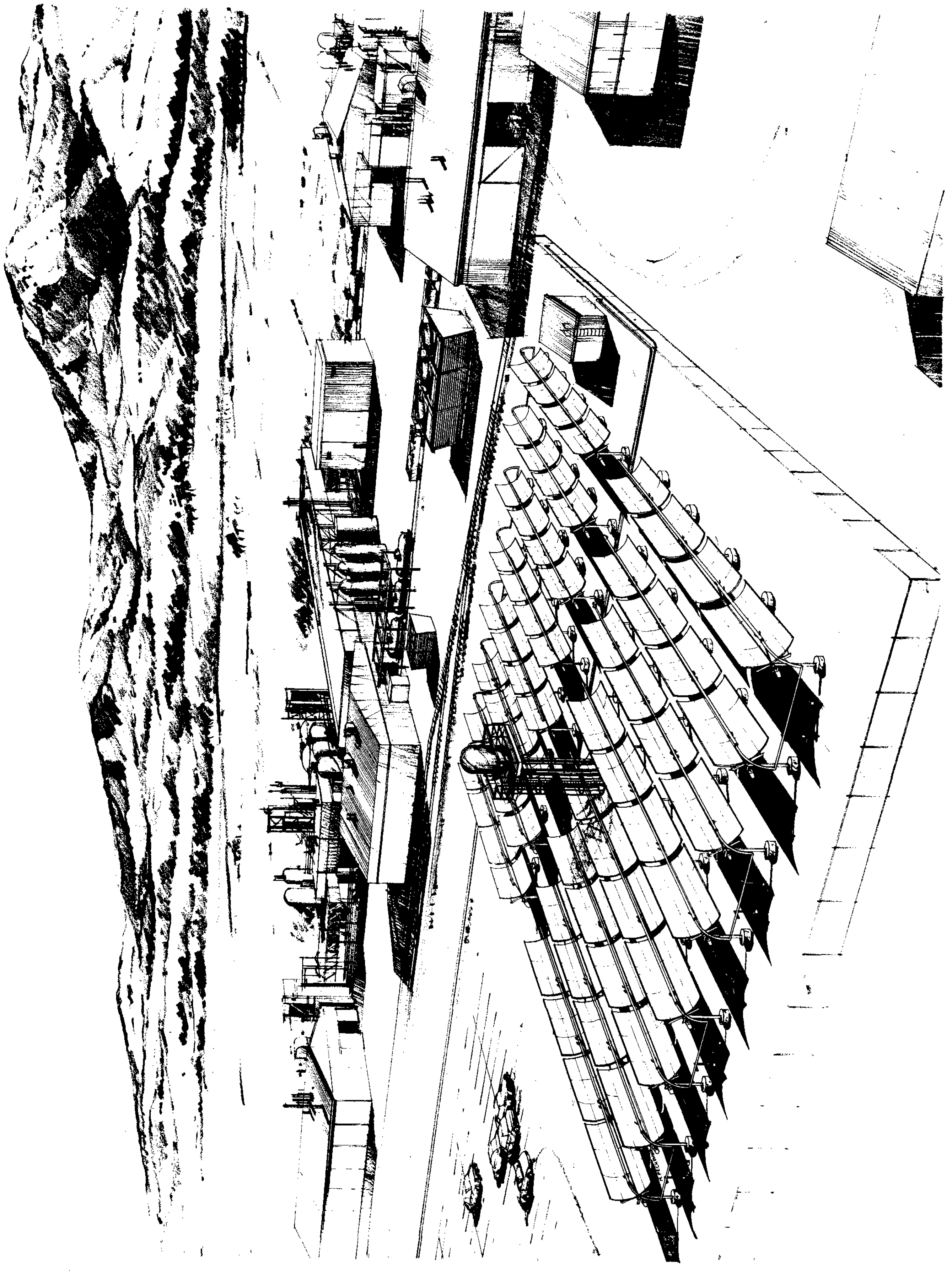


FIGURE 1

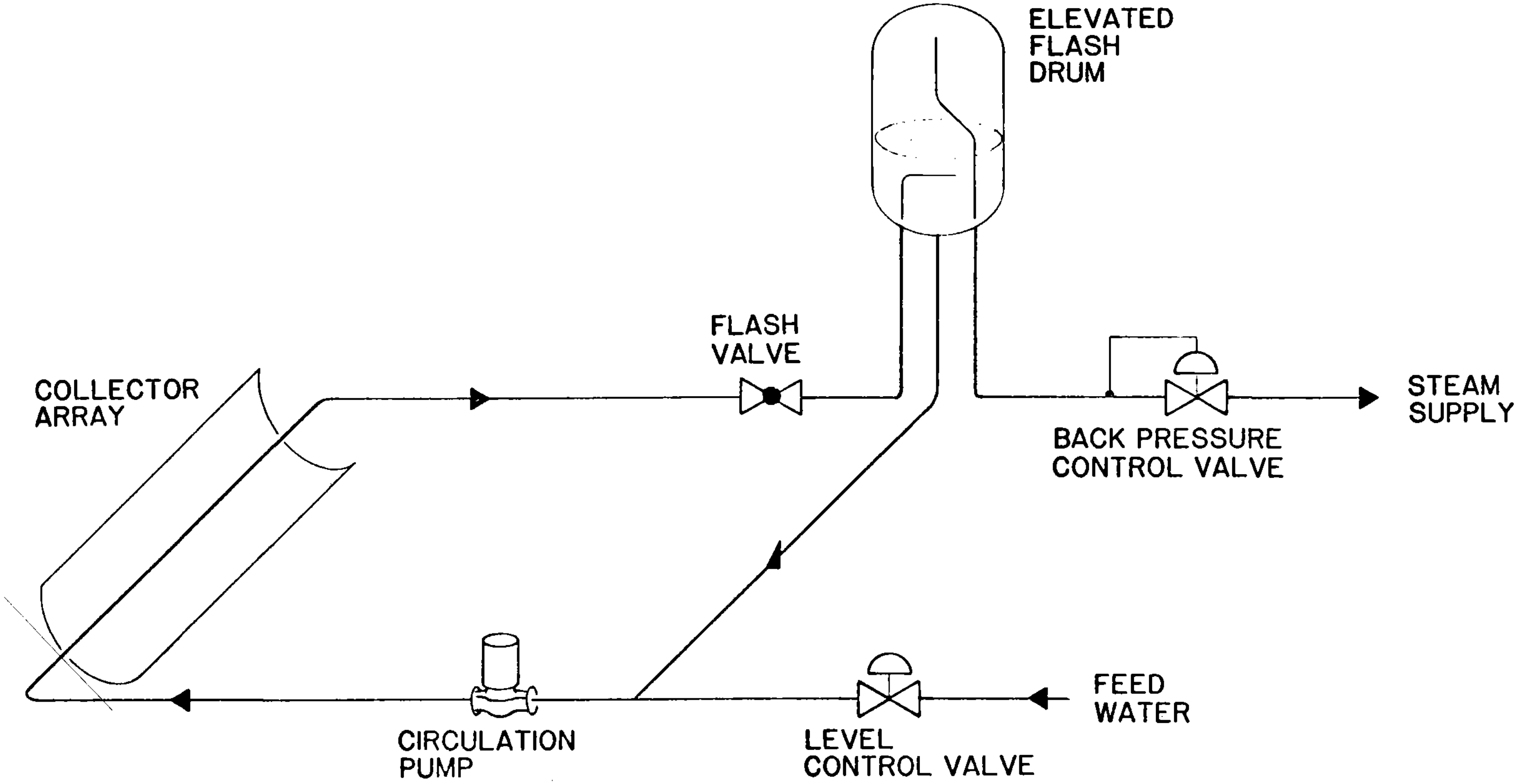
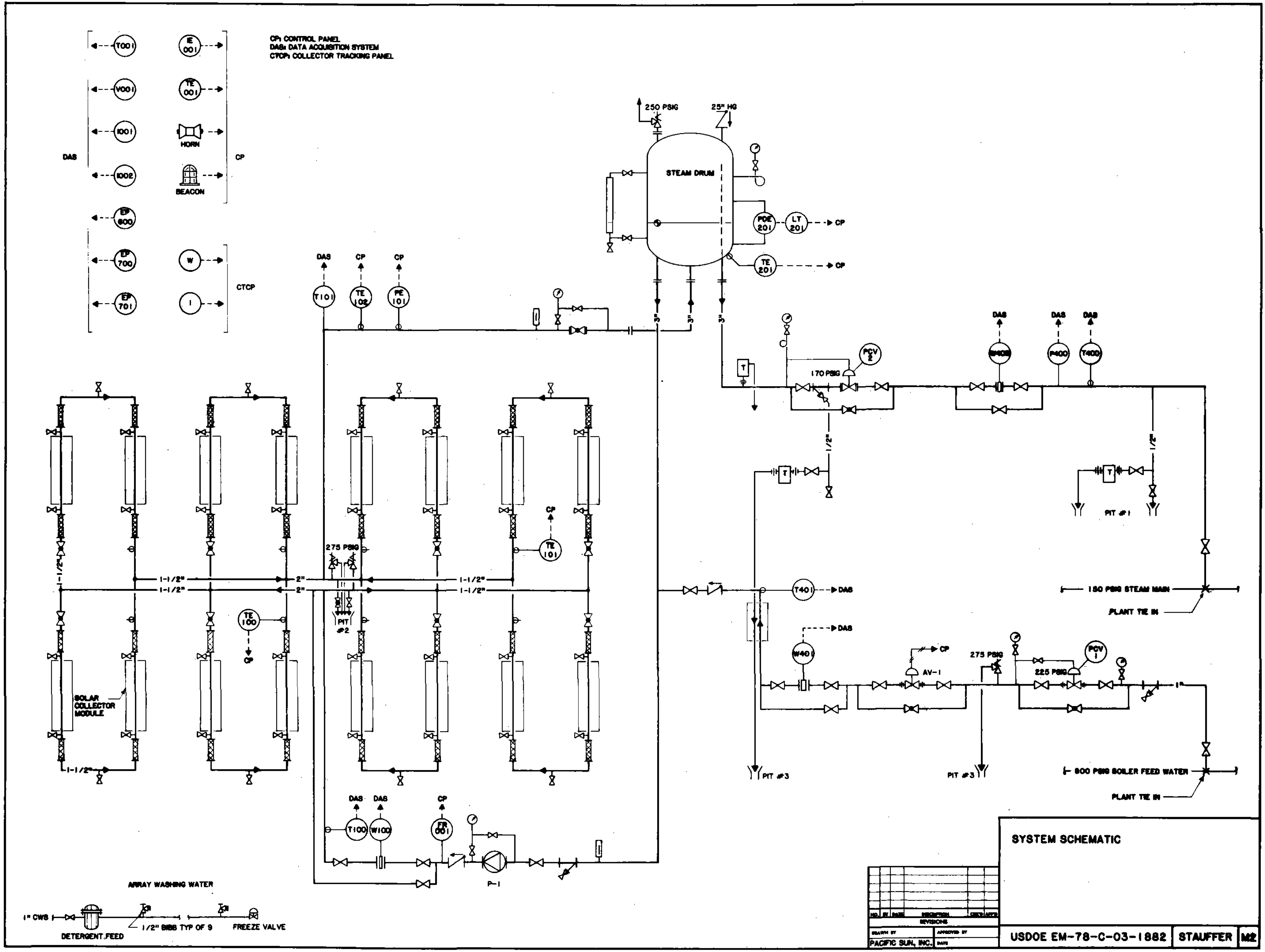

ELEVATED FLASH DRUM
FLASH VALVE
COLLECTOR ARRAY
STEAM SUPPLY
BACK PRESSURE CONTROL VALVE
FEED WATER
CIRCULATION PUMP
LEVEL CONTROL VALVE

FIGURE 2


CP: CONTROL PANEL
DAS: DATA ACQUISITION SYSTEM
CTCP: COLLECTOR TRACKING PANEL
DAS
CP
CTCP
T001
V001
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I002
IE 001
TE 001
HORN
BEACON
EP 600
EP 700
EP 701
W
I
250 PSIG
25" HG
STEAM DRUM
PDE 201
LT 201
TE 201
3"
T101
TE 102
PE 101
PCV 2
170 PSIG
W400
P400
T400
1/2"
T
PIT #1
TE 101
TE 100
275 PSIG
PIT #2
1-1/2"
2"
T401
150 PSIG STEAM MAIN
PLANT TIE IN
W401
AV-1
275 PSIG
225 PSIG
PCV 1
1"
PIT #3
800 PSIG BOILER FEED WATER
SOLAR COLLECTOR MODULE
T100
W100
FR 001
P-1
ARRAY WASHING WATER
1" CWS
DETERGENT FEED
1/2" BIBB TYP OF 9
FREEZE VALVE
SYSTEM SCHEMATIC
REVISIONS
PACIFIC SUN, INC.
USDOE EM-78-C-03-1882
STAUFFER
M2

Figure 3

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR POTATO FRYING

Jack Cherne
TRW Energy Systems Group
Redondo Beach, CA 90278

ABSTRACT

TRW is developing the application of solar industrial process heat to food processing at the Ore-Ida Foods plant in Ontario, Oregon, under the auspices of the Department of Energy. In the just completed Phase I, conceptual design studies and the detail design of the sytem were performed. The end use of the energy is steam at 417°F, 300 psi, heating oil through a heat exchanger to fry potatoes.

The conceptual design study reviewed three methods of producing the steam. These included use of a heat transfer fluid and unfired steam generators, a pressurized water system with an unfired steam generator and a pressurized water flash steam system. The economics of the three systems were examined on both a first cost and life cycle cost basis.

The system selected consists of high efficiency, parabolic trough concentrating collectors generating hot water at 480°F feeding a flash tank which generates steam at 417°F. The steam from the flash tank interfaces with the plant process steam through a simple connection into the steam lines. The design of the system is modular such that it can be augmented to provide whatever requirements are desired. Application to any industrial process using fossil-fired boilers to produce steam is easily accomplished.

Current activities include construction of a 10,000 sq ft array of collectors on the roof of the Ore-Ida potato processing plant. Construction will be completed in June 1980. This system is expected to collect 2.5×10^9 Btu of energy which will produce a net of 1.9×10^9 Btu/year of steam, equivalent to 2.3×10^6 cu ft of natural gas. Production schedules in the plant will result in a steam consumption of 1.3×10^9 Btu/year.

UNDER SPONSORSHIP of the Department of Energy (DOE), TRW is developing a system for supplying industrial process steam from solar energy. The Solar Production of Industrial Process Steam (SPIPS) program is aimed at demonstrating the technology for producing steam in the range between 350°F and 550°F.

Food processing was chosen over pulp and paper or chemical production as the industry application. Food processing plants are generally located in rural areas where large, inexpensive land tracts are available. Furthermore, there is a natural relationship between the need for high insolation levels in crop production and economical solar energy industrial utilization.

The industrial site chosen for the SPIPS program is the potato processing facility of Ore-Ida Foods, Inc., located in Ontario, Oregon. In 1977, over 3.6 billion pounds of frozen potato products were sold nationwide, requiring about 12 x 10^{12} Btu of thermal energy. Eighty-six percent of the processing takes place in the Oregon-Idaho-Washington regions of the Snake River Valley and Columbia basin. The area is desert-like with low precipitation and high annual insolation levels.

The Ontario plant operates three 8-hour shifts per day, six days a week from August through December; and five days per week, three shifts per day from January through July. Two dual-fueled boilers (gas of oil) can each produce 300 psi steam at the rate of 50,000 lbs per hour for the plant's thermal needs. Steam at 417°F is sent to several parallel heat exchangers where a portion of its thermal energy is transferred to cooking oil for potato frying. Forty-five percent of the plant's normal steam production goes to potato frying; the remainder is used in conjunction with condensate blowdown from the heat exchagers for potato blanching and washing. Annual steam demand for the plant is 2.5 x 10^{11} Btu.

SOLAR COLLECTOR ARRAY

Two ground rules of the SPIPS program set by DOE were: the total aperture of the collector array not exceed 10,000 sq ft (the site, however, must have ample room for future expansion) and no major support structure or site preparation be required by the collector field. A site analysis of the Ontario plant showed that the roof of the Packaging Building adjacent to the Potato Processing Building housing the frying lines was the best site choice.

The roof has plan dimensions of 300 x 210 feet with a small slope to the east and west from a north-to-south running peak. The roof surface is composed of tar felt over a layer of mineral wood insulation. The roof structure is composed of precast concrete single and double tee beams. It has sufficient strength to support the weight of the collector array as well as to withstand wind-imposed loads on the array up to 100 mph.

To satisfy the temperature requirements of the Ore-Ida steam demands, linear focusing collection systems were specified. A number of design and performance issues were examined and evaluated from the field of suppliers.

Key issues considered were as follows:

- <u>Collection efficiency</u> — The degree to which incident insolation is delivered to the collector's working fluid. Of particular importance is daily collection efficiency, which controls the total collector area needed to provide a given heat load.

- <u>Field utilization</u> — The ground area of the collector field needed to collect a given amount of energy. This parameter takes into account effects such as shading of one collector upon another at low sun angles and geometric constraints imposed by individual collector design and tracking mechanization.

- Ruggedness and durability — The ability of the system to withstand wind, dust, precipitation and environmental pollutants without failure or significant degradation. Ease of repair and maintenance are important factors related to ruggedness and durability.

- Installation costs — Total installation costs include not only the cost of the solar collector at the site but costs to plumb and insulate lines, provide mounting platforms or bases and to erect the collectors. Prior manufacturing and installation experience is desirable to ensure suppliers' cost estimates are well founded.

Eight different linear focusing systems were reviewed and evaluated. These included: two-axis tracking linear Fresnel lens, linear movable slats, fixed slats and parabolic trough. Collector efficiency was taken from comparative tests performed at Sandia[1], as well as performance calculations provided by individual suppliers on an earlier Solar Total Energy System study[2]. The linear focusing parabolic trough collector represented by Suntec Systems, Inc.'s design was chosen as possessing the best performance-to-cost ratio.

Several Suntec collector arrays were laid out on the roof area and were analyzed in terms of the following constraints and guidelines:

- minimum interference with existing roof penetrations and roof-mounted equipment
- a maximum collector aperture of 10,000 sq ft
- minimum piping requirements
- maximum conservation of rooftop space
- minimum collector surface contamination.

Based upon these considerations, the configuration shown in Figure 1 was selected. It consists of fourteen 80-foot long parabolic trough collectors arranged in a north-south axis orientation. This arrangement results in a collector aperture of 9520 sq ft. The collector modules are placed in such a way that:

- a minimum 6-foot passage exists between rows when the collectors are pointed straight up
- adequate passage area lies between any collector and edge of the roof or existing equipment
- they are remote from effluents of food processing exhausts.

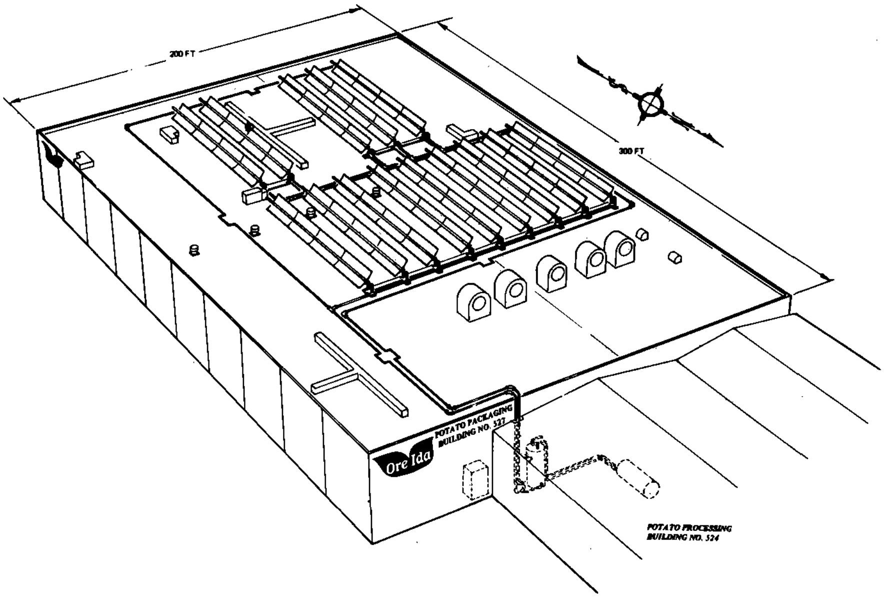

FIGURE 1. COLLECTOR CONFIGURATION

Cool collector fluid flows to an inlet manifold of each collector bank; heated fluid is collected in a central manifold between the two banks and returns to the northeast quadrant of the roof area and then to the steam generation area.

Eighty-foot long modules were chosen over shorter lengths in order to minimize installation and piping cost through reduction in the number of flexible hoses, fittings and risers. Calculations of receiver tube pressure drop and temperature rise showed no unfavorable effect due to using an 80-foot receiver tube.

STEAM GENERATION CONCEPTS

The design of the heat transfer loop through the collectors and the method of generating steam were major concerns in the trade-offs of SPIPS conceptual designs. Three approaches for steam generation were analyzed and evaluated. The three systems are referred to as:

- Heat Transfer Fluid/Steam System
- Pressurized Water/Flash Steam System
- Pressurized Water/Steam System.

Heat Transfer Fluid/Steam System (HTFSS)

The HTFSS concept uses a low vapor pressure, non-aqueous heat transfer fluid in the collector field to deliver heat to an unfired steam generator. The latter device produces the steam needed for heating cooking oil in the fryer as well as lower pressure steam used in downstream potato processing steps. Hot fluid at 480°F leaves the collector field from the outlet manifold connecting the 14 receiver tubes and flows to an unfired steam generator. After giving up its heat, the heat transfer fluid returns to an expansion tank at about 470°F. The expansion tank also functions as the interface for system pressurization through a nitrogen blanket. Products of heat transfer fluid decomposition may be drawn off and vented from the tank. The fluid then completes the heat transfer loop by being pumped back to the collector field inlet manifold. The collector fluid outlet temperature is controlled by bypassing a portion of the fluid around the circulating pump; throttling of the circulating fluid is also a possible control means.

A number of potential heat transfer fluids were identified. These included Caloria HT-43, Therminol 66, Dowtherms A and G, and silicone oil. The first four were rejected due to their relative degrees of toxicity, carcinogenic potential and flammability. The remaining fluid is a silicon compound having attractive properties as a heat transfer fluid, i.e., low freezing point, high flash and fire points, and no known toxic or carcinogenic properties.

Although silicones are used in medicines and cosmetics, they have not yet received Food and Drug Administration clearance as a food additive. To prevent possible silicone oil penetration into the plant's steam line and its subsequent direct contact with the potatoes, an intermediate steam heat transfer loop is required.

Presuming the use of a silicone oil fluid heat transfer, the remainder of the HTFSS behaves as follows. In the unfired steam generator, heat from the fluid is transferred to water producing steam at 450°F (425 psia). This steam then flows to another unfired steam generator and gives up its heat of vaporization to produce steam at 417°F (300 psia) for delivery to the plant steam heater at the fryer.

Condensate from steam generator No. 2 is returned to generator No. 1 through a recirculation pump. The feed for generator No. 2 is treated Ontario city water, which may be supplied from either a deionizer and deaerator dedicated to the SPIPS, or from the main water treatement system employed in the plant's boilers. The system is sized for a peak energy delivered to the heat transfer fluid of 2.0 x 10^6 Btu/hr.

Pressurized Water/Flash Steam System (PWFSS)

In the PWFSS concept, the collector receiver tubes are cooled by circulating pressurized water. The hot water then undergoes a homoenthalpic expansion to the desired process steam pressure. As it expands, it flashes into low quality steam; the steam is separated and delivered to the fryer steam main.

Figure 2 shows the PWFSS process flow. Hot water at 477°F, 600 psia, flows from the collector field to a flash tank where it is throttled to 300 psia, producing about 8 percent quality steam at 417°F. The hot water portion, or "drips", is combined with makeup water from either a

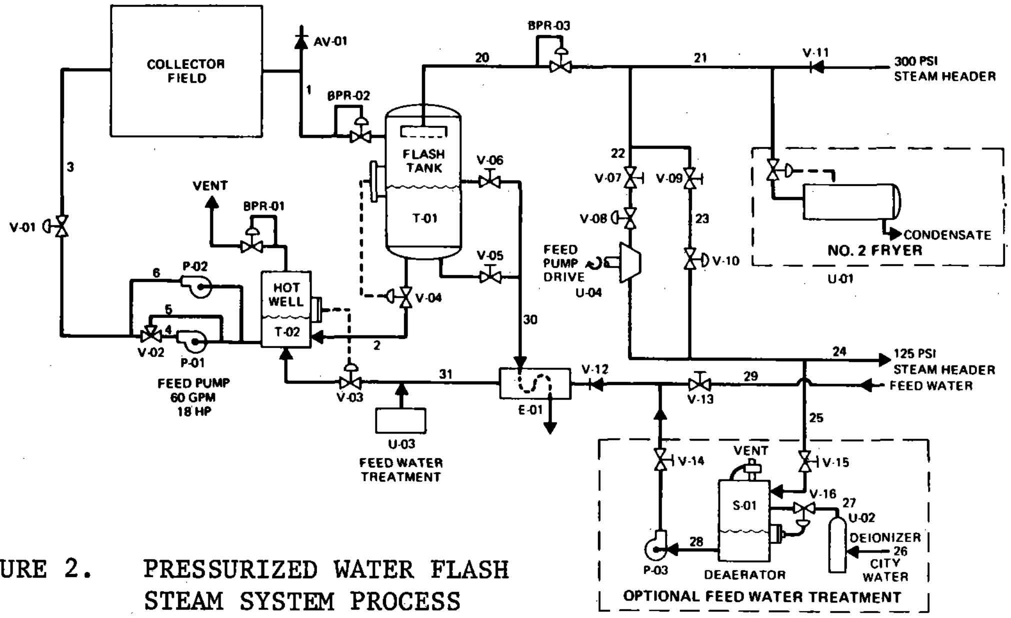

FIGURE 2. PRESSURIZED WATER FLASH STEAM SYSTEM PROCESS FLOW DIAGRAM

stand-alone dedicated feed water treatment system, and returned to the collector field through a feed water pump. Continuous or periodic blowdown of the flash tank is required to prevent solids buildup. The system feed water pump is relatively large due to the high pressure differential and mass flow rate it must pump.

Pressurized Water/Steam System (PWSS)

The PWSS contains elements from both HTFSS and PWFSS concepts. Pressurized water at 600 psia and 477°F gives up sensible heat in an unfired steam generator producing the required 417°F (300 psia) saturated steam for the fryer. Cooled pressurized water is returned to a nitrogen-blanketed expansion tank volume from which it is pumped back to the collector field. As in the HTFSS, makeup-treated water is added to the inlet of the steam generator through a liquid level controller.

Note that, although the PWSS collector field pressure is the same as in the PWFSS, the circulating pump of the former system is much smaller since it only has to work against the pressure drop of the field piping and not the flash pressure drop of the PWFSS.

SYSTEM COMPARATIVE ANALYSIS

The system schematics and parameters discussed above were the basis for preliminary equipment and piping sizing. Where there was a question about appropriate equipment or piping size, several sizes were analyzed. This preliminary selection of equipment allowed the system's mechanical parameters to be defined and a preliminary cost estimate to be prepared.

In general, the results of this estimate indicate that the differences in the total costs for the piping, valves, insulation and pumping for the three systems considered are small. Unfired boilers are the most expensive single item, excluding the collectors, within the systems considered. The pressurized water/flash steam system has a lower initial cost since it does not require such a boiler. This system, however, has the highest operating cost in terms of the electrical requirements for pumping. The flash system has slightly lower heat losses than the others since it has shorter piping runs and operates at lower average temperatures.

Table 1 summarizes the results of the conceptual design analyses. Although it was initially believed that the HTFSS system would be the most cost effective, the requirements for a secondary heat transfer loop increased the concept's cost and resulted in additional heat transfer losses through added pipe lengths, fittings and higher temperature differentials needed to drive the heat transfer.

TABLE 1. SUMMARY OF CONCEPTUAL DESIGN TRADE-OFF ANALYSES

Concept	Installed Cost ($) *	Present Value of Pumping Costs ($)	Technology Unknowns	Safety	Use of Plant Space	Solar Energy Utilization (Btu/ft^2/yr)	Reliability and Maintenance
Heat Transfer Fluid/Steam System (HTFSS)	170,200	2,400	<2 years operating experience with silicone Fluids	Low field pressure; slight fire hazard	Two steam generators and pumps	2.71×10^5	Most complex system; control of heat transfer fluid thermal degradation
Pressurized Water/ Steam System (PWSS)	151,700	1,200	Limited experience with high pressure, high temperature receivers	High field working pressure; no fire hazard	Single steam generator and pump	2.90×10^5	Control of water quality in field loop to prevent corrosion
Pressurized Water/ Flash System (PWFS)	129,700	8,600	Limited experience with high pressure, high temperature receivers	High field working pressure; no fire hazard	Flash tank and pump	2.93×10^5	Control of water quality in field loop to prevent corrosion; severe service for circulating pump

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*Cost of critical components

Of the two concepts employing water as the collector fluid, the PWFSS has a 17 percent lower initial cost and 12 percent lower life cycle cost (excluding collector costs). The incremental capital cost of the flash system's larger pump over the pump of the pressurized water steam system does not offset the incremental cost of the latter's unfired steam generator. Over the life of the installation, the PWFSS's additional cost of electricity is not enough to offset the initial investment differential. Furthermore, the PWFSS appears to have lower parasitic heat losses and is more readily fit within the limited space allocated for the SPIPS steam generating equipment.

ENERGY SAVINGS AND DISPLACEMENTS

Table 2 summarizes the annual energy savings and fossil fuel displacements estimated for the SPIPS installation based upon the PWFSS design concept. Models of diurnal solar insolation in the Ontario area based upon historical data were used as input to the collector array. These data, coupled to experimental data on Suntec's collector and historical plant operation schedules, were used to estimate steam production from the SPIPS installation. The results indicate that the SPIPS system will produce about 7.3% of the current annual needs of the frying line. SPIPS will increase the electrical demand of the plant; however, on an energy equivalent basis, the increased demand is only about 3% of the fossil energy saved.

TABLE 2. SPIPS ENERGY SAVINGS AND DISPLACEMENTS

Annual steam supplied by SPIPS	2.5×10^9 Btu
Parasitic electrical energy consumed in pumping (direct thermal equivalent)	1.0×10^8 Btu
Net energy generated	1.9×10^9 Btu
Natural gas displaced	2.3×10^6 cu ft

CONTRACT STATUS

The designed described above reflects the conceptual design analysis performed during Phase I of DOE Contract DE-AC03-78CS 32197 with TRW Energy Systems Group. The author was the principal investigator and may be reached at (213) 536-1955. Phase I, which included the detail design of the system, has been completed. Construction of the project is underway and is scheduled for completion by July 1980. Phase III, which is to start in August 1980, will consist of a 15-month test and evaluation period.

REFERENCES

1. J. A. Leonard, "Linear Concentrating Solar Collectors — Current Technology and Applications," SAND 78-09419, July 1978.

2. "Conceptual Design Solar Total Energy Large Scale Experiment Number 1," TRW Report No. 97073.003, prepared for U.S. Department of Energy, Albuquerque Operations, October 21, 1977.

A SOLAR COLLECTOR AND INDUSTRIAL HEAT PUMP SYSTEM FOR PROCESS HOT WATER FOR AN ALUMINUM ANODIZING LINE

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EDITOR'S NOTE

This paper was originally presented at the Solar Industrial Process Heat Symposium at College Park, Maryland, September 19-20, 1977, but was not included in the Proceedings. It is included in these Proceedings for historical interest, and because a description of the system is not available elsewhere.

ABSTRACT

General Extrusions, Inc., Youngstown, Ohio and Solar Energy Engineering, Poland Ohio, have designed an industrially-oriented solar collector. They designed and constructed a system utilizing 4,400 square feet of these collectors and a specially-designed Westinghouse Templifier industrial heat pump to heat the alkaline-clean tank of GEI's anodizing line. Work was initiated on this project in the summer of 1976 and completed in September 1977. The system is capable of producing over 500,000 Btu/hr (146 kW) at 190°F (88°C) during a sunny noontime.

SYSTEM DESCRIPTION

The system has been operating very well during the past 14 months. No significant solar or mechanical problems have been encountered. The array was designed for light weight and bolted directly to the steel deck roof. It survived the year's weather including all-time record winter winds in January with no problems at all and no roof leaks. The heat pump has operated faultlessly and has demonstrated a dynamic range of down to 18°C (65°F) input to the evaporator and up to 110°C (230°F) output from the condenser. Fluid return from the collectors has ranged up to 105°C (220°F) in full-flow normal operation. In September 1978, GEI received a grant from the Ohio Department of Energy to install a mini-computer-based monitor system (CEMS). Special attention will be directed toward evaluation of the industrial heat pump as interfaced with the solar system.

In the summer of 1976, work was begun by General Extrusions, Inc. (GEI), Youngstown, Ohio, and Solar Energy Engineering (SEE), Poland, Ohio, on the construction of an industrially-oriented solar collector for GEI's industrial solar system. GEI and SEE had submitted a proposal on this project to produce industrial process hot water in response to an ERDA request for proposals in January, 1976. Evidently the project was not far enough along to warrant assistance by ERDA, and no funds were available. A subsequent proposal to the Ohio Energy Resource and Development Agency resulted in funding in the amount of $31,125.00, and was the only solar project funded at any level by OERDA. Work continued throughout the winter, and the collectors were shown at the American Section Meeting of the International Solar Energy Society (ISES) in Orlando, Florida, on June 6-10, 1977. Construction was begun in August, 1977, on the 100 collector modules for GEI's industrial solar system. The first collectors were installed August 12, and the array was first activated on September 10, 1977. Full-scale testing is under way at this time.

The collector is now manufactured by the newly created General Solar Systems Division of General Extrusions, and is the Model LTC-367. It is 3.0 by 1.36 m (119" x 54") overall, with 3.04 m^2 (32.7 ft^2) effective capture aperture. The concentration ratio of 3.67 is accomplished by the half-parabolic reflector reflecting the insolation onto a finned tube absorber. The complete construction details were presented at the American Section Meeting of ISES in Orlando, Florida, in June, 1977. (1)

The solar collectors are mounted on the anodizing storage room roof at GEI in four rows of twenty-two columns, plus two back sections of two rows of three columns. The array of 100 modules creates a static load on the roof of approximately 30,000 pounds which is distributed over about 8500 square feet. Though the flat roof was not initially designed for a solar array, this comparatively light load is well within the capability of the roof. The fluid connections are designed to have strings of three collectors in series and four of these strings in parallel to form a block. Eighty-four collectors are plumbed this way, with four additional strings in two sets of parallel flows. The last four collectors are in parallel, and form the public viewing and demonstration end of the array.

The circulating fluid is a light oil to avoid the problems associated with aqueous systems. A gear pump capable of 80 gpm is used to circulate the fluid, with a bypass loop included to allow regulation of the flow through the array. All lines on the roof are insulated with three-quarter-inch-thick insulation to minimize heat losses. A 550-gallon insulated tank is used as an expamsion tank and fluid reservoir for the 400 gallons of solar fluid.

The operation of the system to provide heat to the alkaline-clean tank of the anodizing line is most easily described by reviewing each of the five typical operating modes. All modes are switched from the main control panel, and valves and pumps are electrically actuated.

> Mode 1: Heating Directly from Solar Collectors. (Figure 1) The solar collector fluid is circulated through one side of the heat exchanger, and the alkaline solution is pumped through the other side. The alkaline-clean fluid flow may be adjusted from 0 to 100 gpm. This mode is selected when the solar system is delivering heat to the 180°F (82°C) cleaning solution directly.
>
> Mode 2: Heating Incorporating the Solar Collectors, Heat Pump and Storage. (Figure 2) In this mode, the solar-heated fluid transfers the heat through the heat exchanger to a rinse water from the 3600 gallon rinse tank #3. Rinse water flow is adjustable from 0 to 100 gpm. This water then supplies the evaporator of the specially-designed Westinghouse Templifier heat pump. The output from the condenser is taken by a water circulation loop which transfers the heat through another heat exchanger to the alkaline-clean solution. The corrosive nature of the solution being heated was always a consideration in the system design, and forced the use of more components and expense than would be necessary for an easier project such as process hot water. In this mode, energy may be supplied to the storage or removed, depending on the heat produced by the solar array. The output of the heat pump to the alkaline-clean is held constant in either situation.
>
> Mode 3: Heating from Solar Collectors and Heat Pump. (Figure 3) A small quantity (40 gallons) of the rinse/storage water is used as the circulating fluid from the solar collector heat exchanger to the heat pump evaporator. This mode is similar to Mode 2 except it removes the storage from active participation. Mode 3 will be run when the solar array can meet the energy requirements of the alkaline-clean tank, but not at 190°F. The heat pump will deliver the heat at the high temperature with a COP directly related to the temperature from the solar loop.
>
> Mode 4: Heating from Storage. (Figure 4) During times of no available solar energy, the heat pump will draw energy from the storage tank and deliver it to the alkaline-clean tank. This is not a mode which will be used often, due to the low COP under high ΔT conditions. When business considerations change, we will drop the alkaline-clean solution temperature to 140°F (60°C) and Mode 4 will be much more attractive.

Mode 5: Heating Storage from Solar Collectors. (Figure 5)
When the alkaline-clean tank energy needs are met, the solar heat will be transfered to the rinse/storage tank.

The basic control of the system is manual at this time. The tests and detailed operating parameters for each possible combination are thus more easily controlled. We did not design and install a fully-automated control system in these initial stages for three reasons: information, time and money. We wanted the operational flexibility offered by manual controls to establish a data base to incorporate into an accurate automatic control system. Too often a system designer will try to "guess-timate" unknown performance features, and fail to correctly design the the operational algorithm. The other two items, time and money, are next to be attached in the evolution of the GEI/SEE industrial solar system.

Monitoring and data acquisition will come from a variety of instrumentation components. An Eppley Pyronometer will provide the signal to a strip chart recorder. Thermocouple outputs will be recorded on another strip chart recorder. General monitoring and adjustments are facilitated by numerous thermometers throughout the system. Fluid flow is measured by three turbine flow meters with capacities up to 120 gpm.

Temperature control of the Templifier is set by the temperature of the inlet water to the condenser section. This unit was specially modified for us to allow temperature control based on the inlet fluid to the evaporator. This allows testing of the solar array at specified temparatures by adding or shedding load to hold constant temperatures. Special mention must be made of the Westinghouse effort to build this special Templifier. It is the largest reciprocating heat pump model they build, and is the only unit with the high temperature output required, and dual control functions.

Summary of the activities and projects to date with the General Solar Systems Division of General Extrusions and Solar Energy Engineering can be done quite simply. An innovative collector for industrial and commercial applications has been designed and mass produced. The first large-scale industrial system of solar collectors and a heat pump in the United States has been designed and installed, and is now operating.

Reference

1. Duane F. Rost, Gene J. Ameduri, Charles K. Alexander, and Herbert F. Schuler, "A Solar Collector for Industrial and Commerical Applications," in *Proc. Annual Meeting Amer. Sect. Intern. Solar Energy Soc., 1977* (International Solar Energy Society, Orlando, 1977) vol. 1, pp. 34-7 to 34-11.

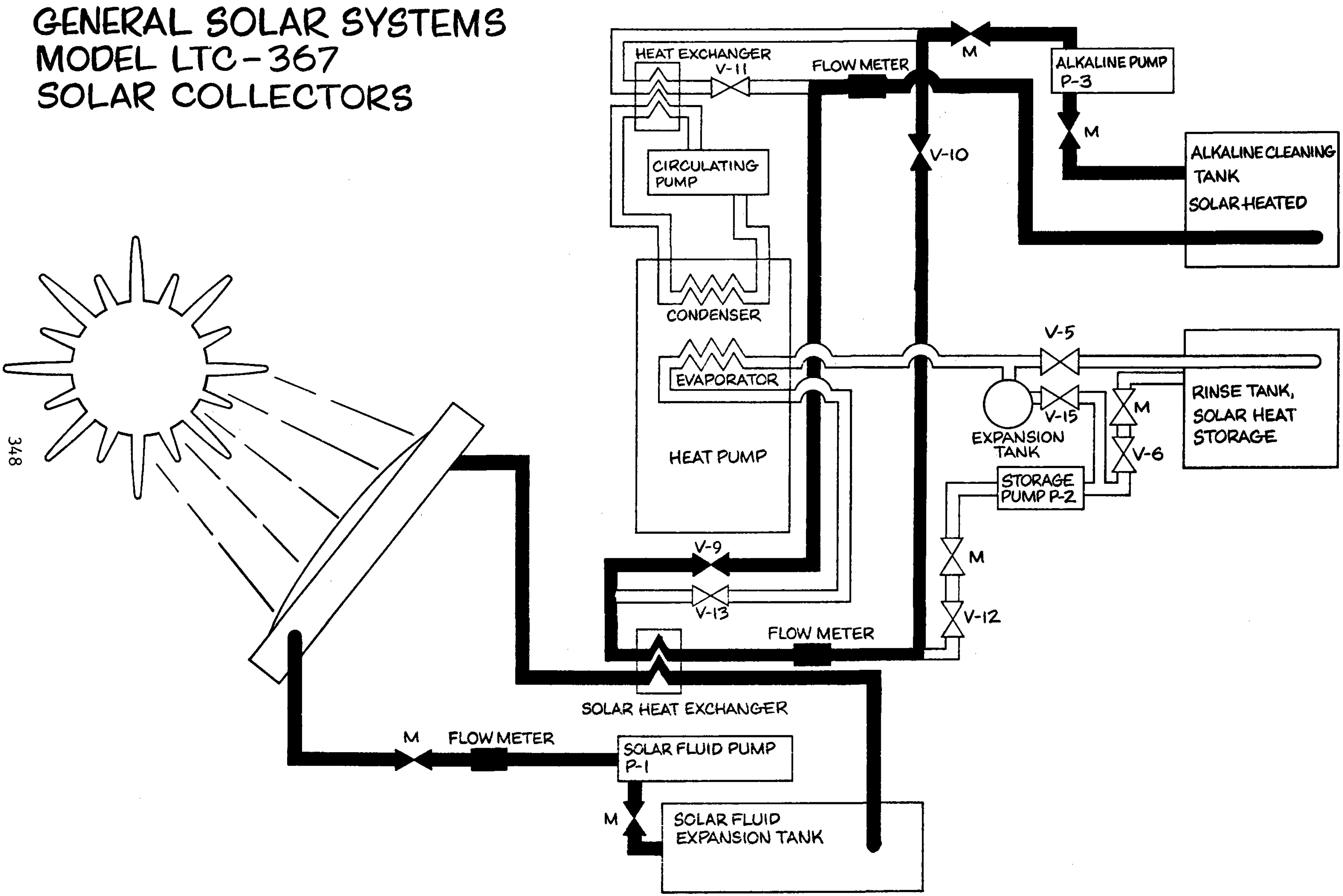

Figure 1. Mode 1: Heating Directly from Solar Collectors

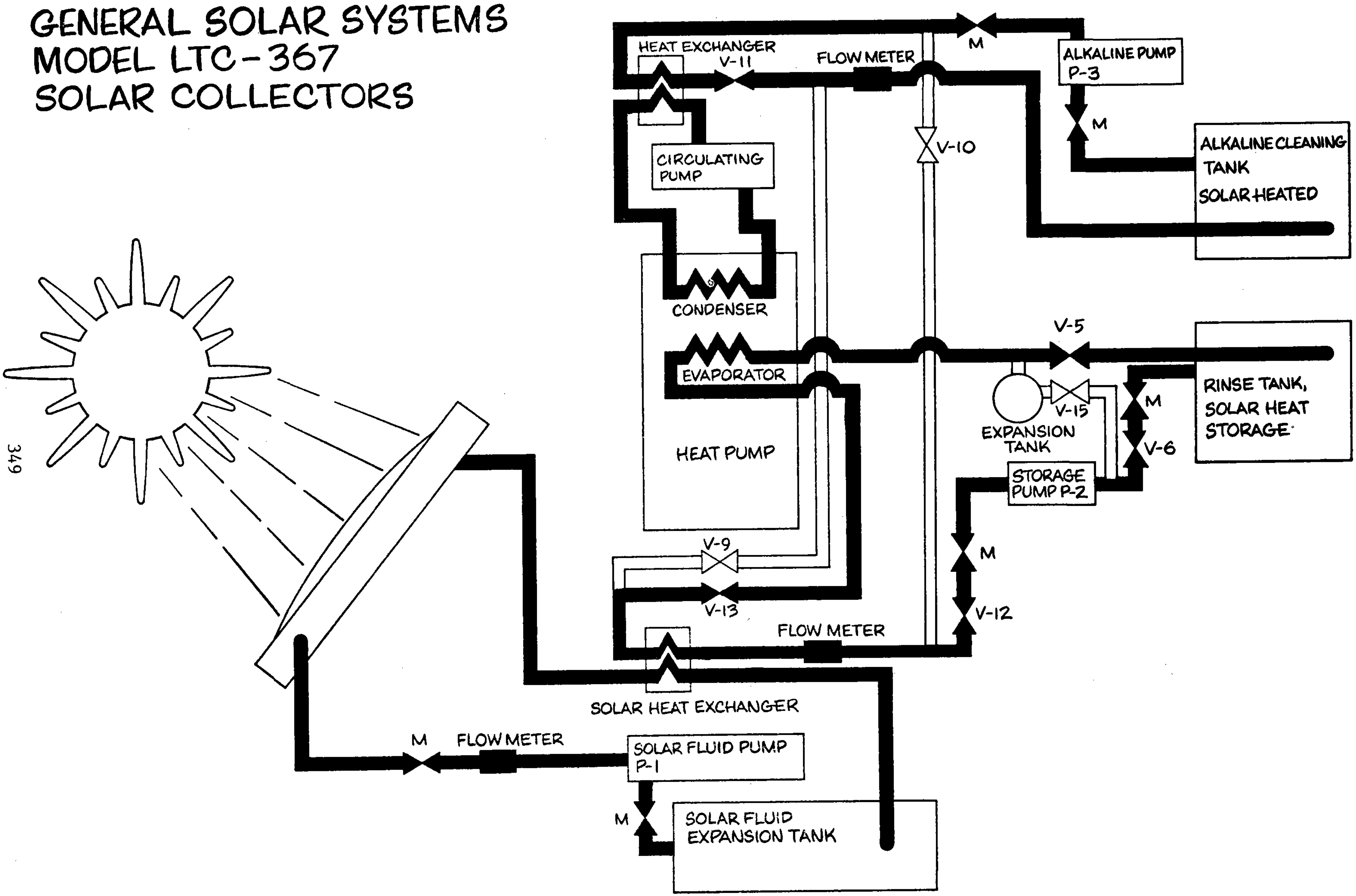

Figure 2. Mode 2: Heating Incorporating the Solar Collectors, Heat Pump and Storage

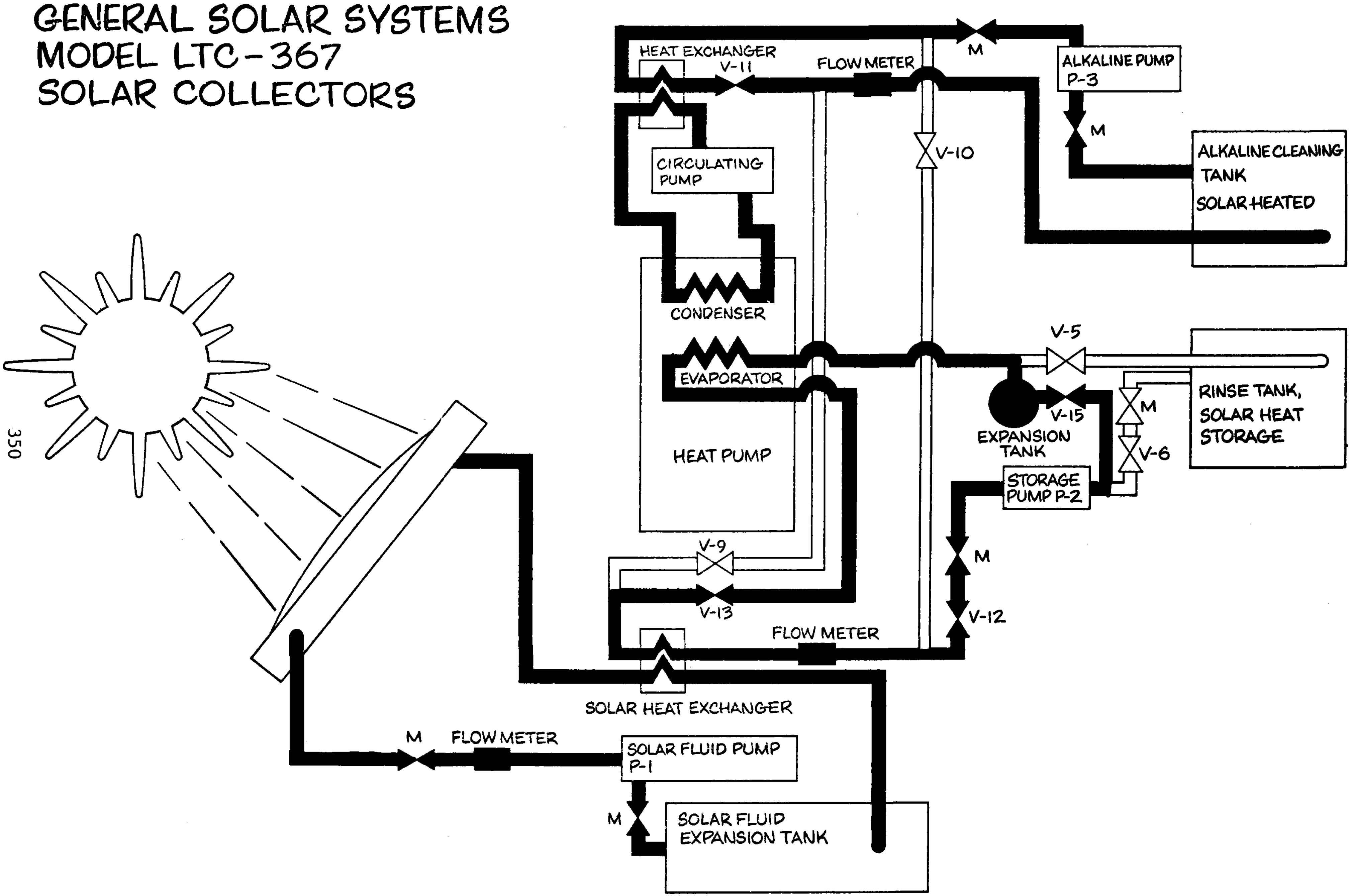

Figure 3. Mode 3: Heating from Solar Collectors and Heat Pump

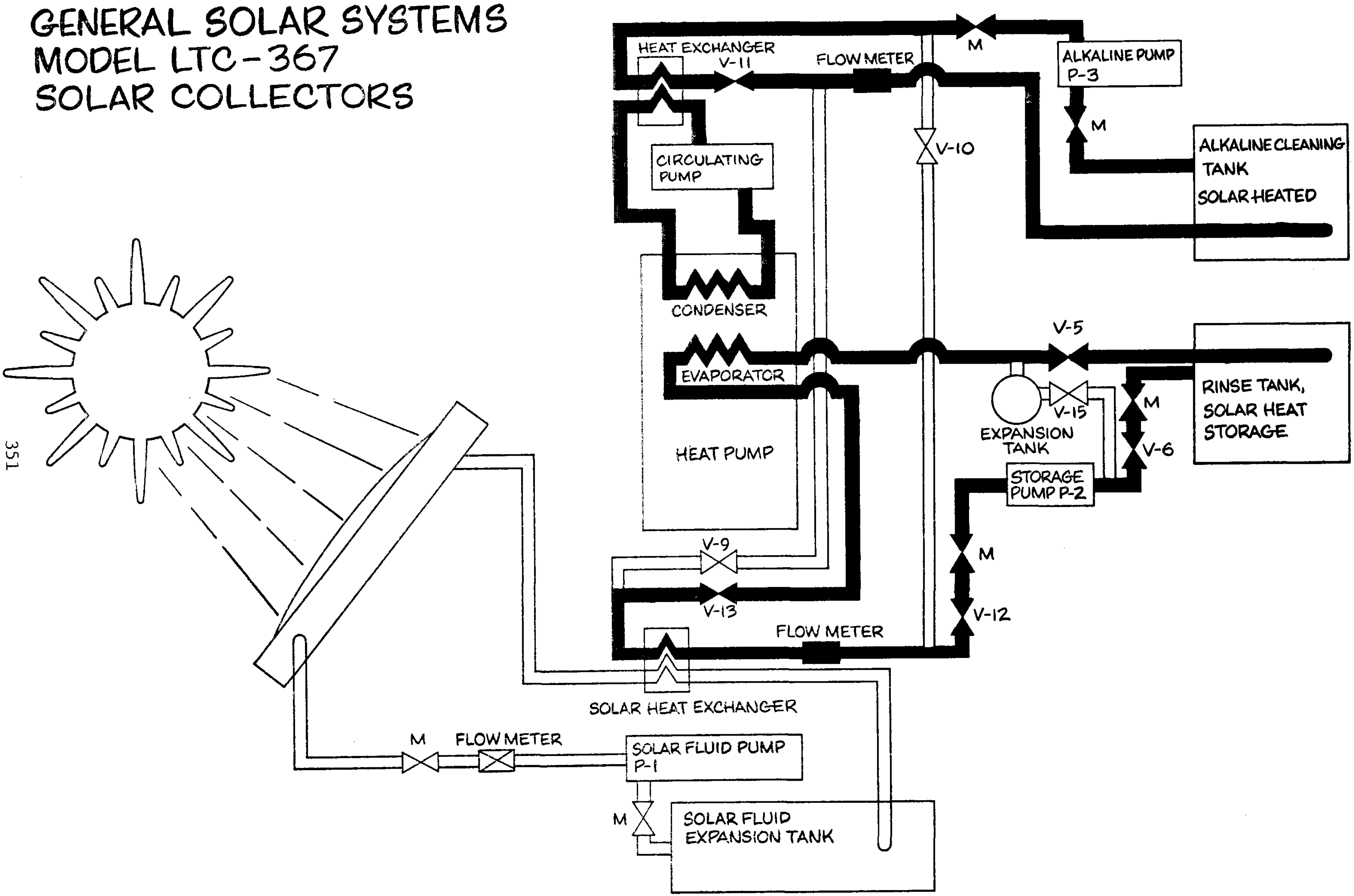

Figure 4. Mode 4: Heating from Storage

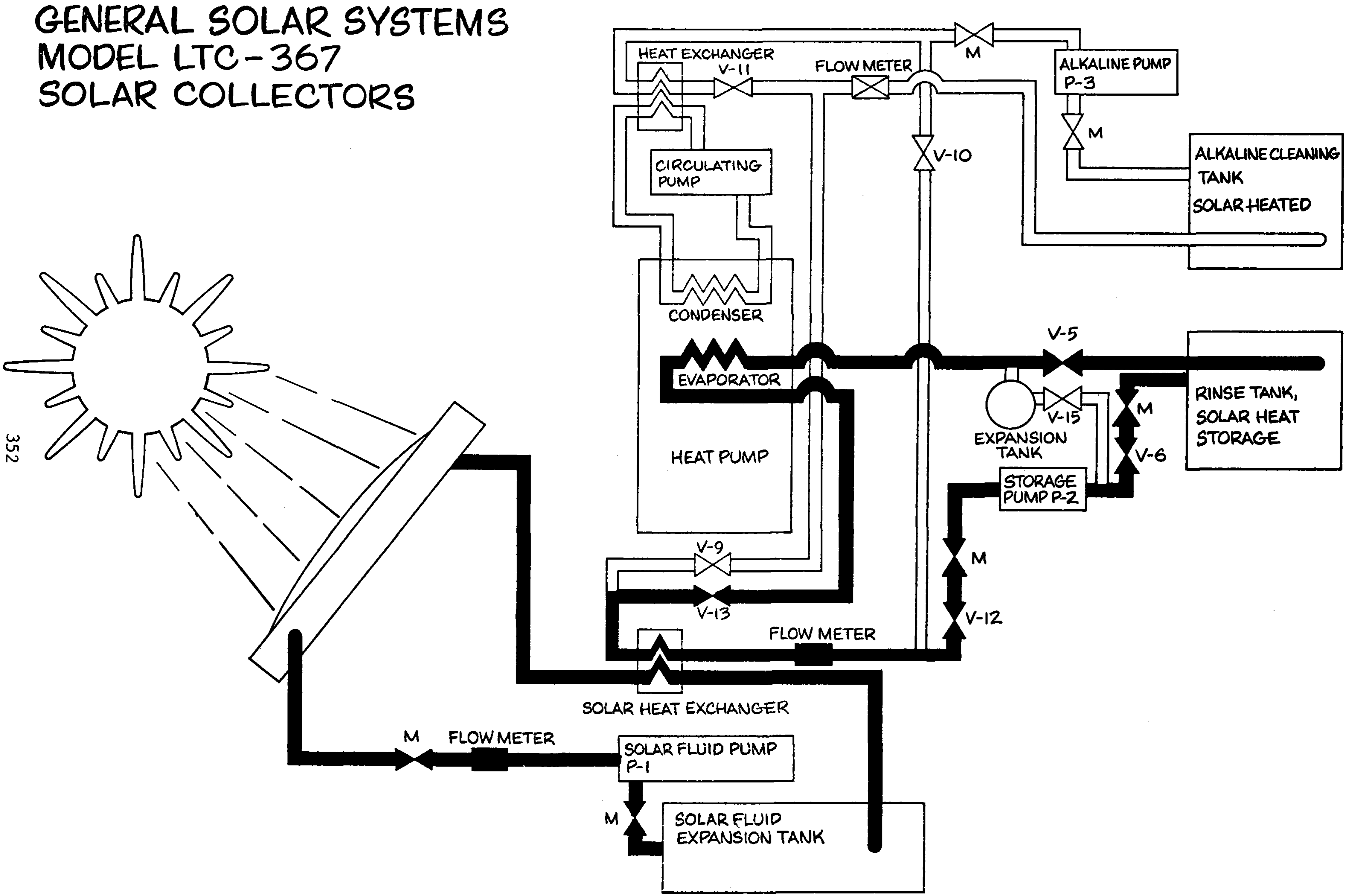

Figure 5. Mode 5: Heating Storage from Solar Collectors

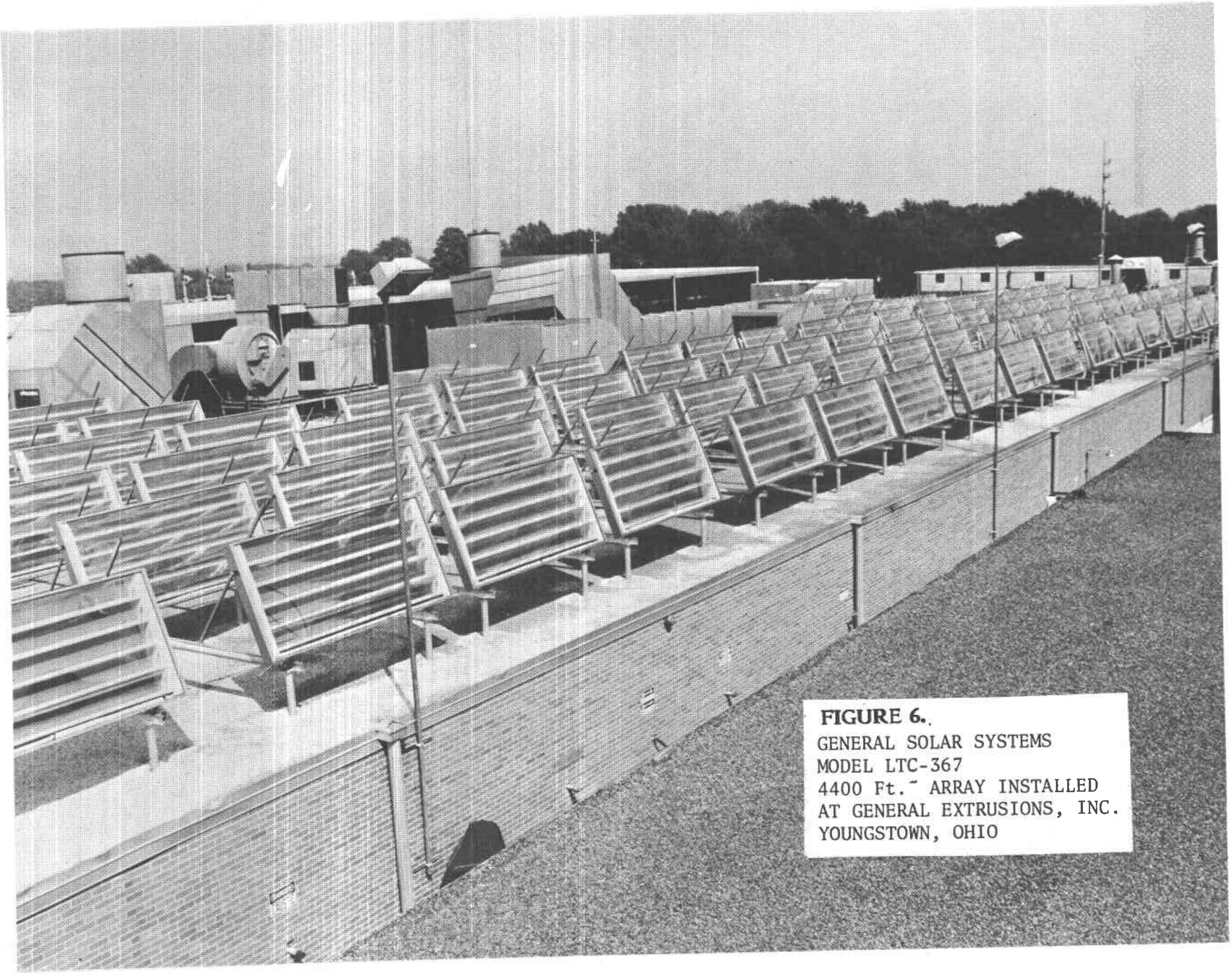

FIGURE 6.
GENERAL SOLAR SYSTEMS
MODEL LTC-367
4400 Ft.^{2} ARRAY INSTALLED
AT GENERAL EXTRUSIONS, INC.
YOUNGSTOWN, OHIO

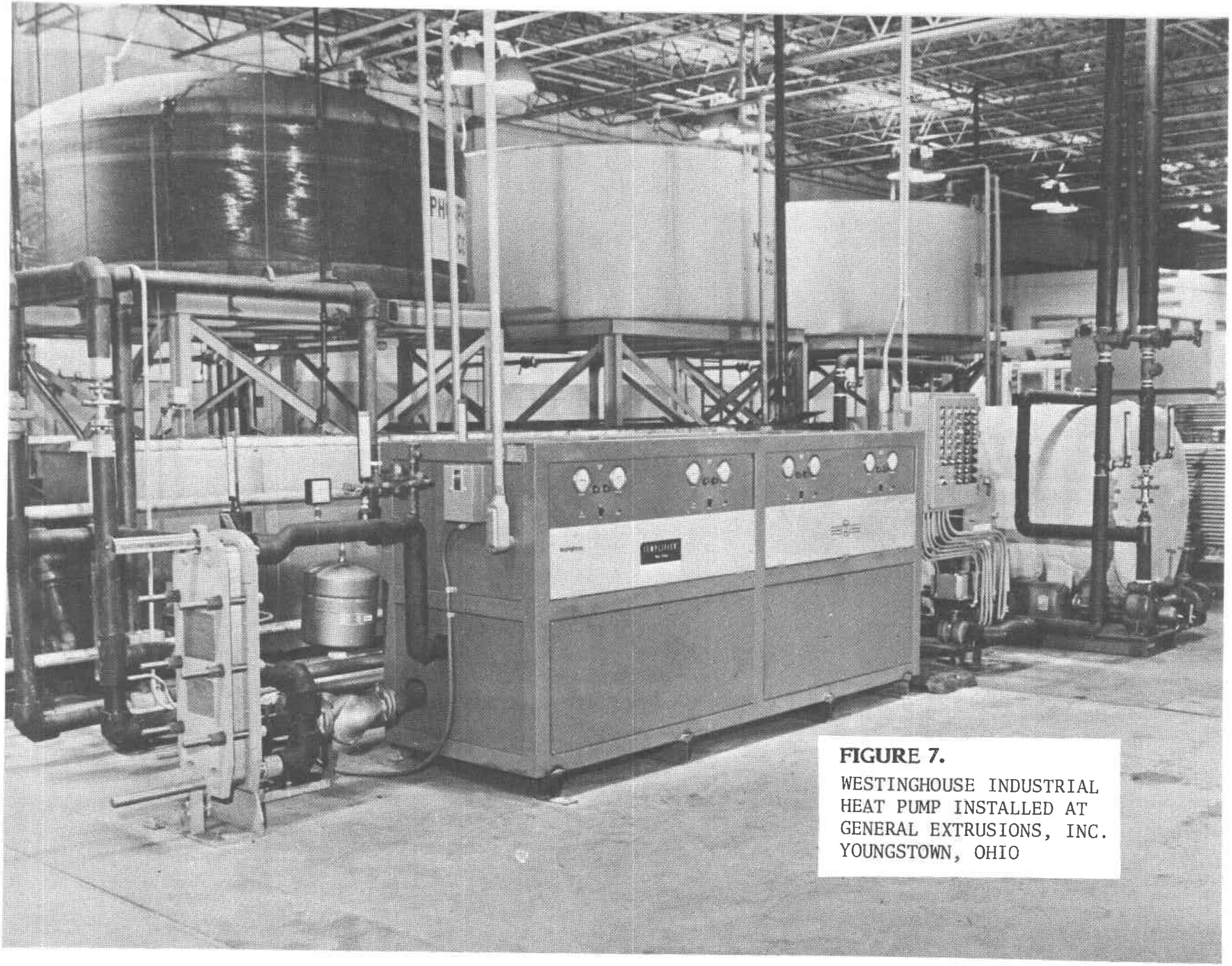

FIGURE 7.
WESTINGHOUSE INDUSTRIAL HEAT PUMP INSTALLED AT GENERAL EXTRUSIONS, INC. YOUNGSTOWN, OHIO

Technology Assessment - I

AN OVERVIEW OF SOLAR POND TECHNOLOGY

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ABSTRACT

An overview of the current technology of solar ponds is presented, with emphasis on salt gradient ponds. The current pond programs of both the United States and Israel are described, and several proposed U.S./Israel cooperative pond projects are discussed. Possible pond applications to industrial processes are explored, leading to the conclusion that under appropriate conditions, ponds are a highly promising method of collecting and storing solar energy for industrial process heat (IPH).

I. INTRODUCTION

There are two distinct approaches to developing cost-effective solar technologies. One approach is to start with a concept which is certain to "work," and to pursue development aimed at making it cheap. Another quite different approach is to take a concept which is inherently cheap, and to focus R&D on making it work. Both approaches are necessary and desirable in order to bring about widespread utilization of solar energy in the U.S. energy economy. The first approach is typified by the national program to promote increased efficiency and reduced costs, through mass production and innovative manufacturing methods, for such factory-produced solar technologies as flat-plate collectors, line-focus concentrators, photovoltaics and evacuated tubular collectors. Examples of the second approach include passive solar heating and/or cooling; large-area site-built collectors of low-cost materials, for example, plastics, asphalt or recycled materials such as beer cans and broken glass; underground aquifer thermal storage; and solar ponds.

While the national program for solar thermal applications has now advanced beyond the early Energy Research and Development Administration (ERDA) phase of funding a large number of promising but untried ideas [1], I believe that it is still much too early to put all of our R&D eggs in one technological basket. Line-focus concentrators will certainly work and can undoubtedly be manufactured more cheaply than at present, but I doubt that they are a universal answer for all thermal applications below 600° F. In particular, the claim made by at least one parabolic trough proponent [2] that troughs perform as well as flat-plate collectors at temperatures as low as 43° C (110° F), for about equal cost, must still be verified by actual side-by-side performance comparisons under a variety of direct/diffuse insolation conditions, over a time period long enough to show any performance decrease due to materials degradation, and using actual commercial hardware. While this study provides some useful preliminary results, to be definitive, the comparison of troughs to flat-plate collectors should be broadened to include other low- and mid-temperature collectors such as evacuated tubes, non-focusing concentrators (with or without evacuated receivers), and ponds.

As used here, the term "solar pond" indicates a device in which water plays a significant role in both the collection and storage of solar energy. This imprecise definition is necessary because the term is presently in common usage to denote at least two quite different concepts, the salt gradient non-convecting pond and the "shallow solar pond." These are described in the following section. One feature that ponds have in common is that water is heated by solar radiation either directly and/or "almost directly" (e.g., by resting upon a dark absorbing surface). Also, the water is not moving through or past an absorbing surface as occurs in a flow-through or trickle collector. The heated water also provides thermal storage on a daily or quasi-seasonal basis.

Solar ponds in general and salt gradient ponds in particular are unique in offering the potential of very cheap combined collection and long-term storage for a multiplicity of low-temperature thermal applications, such as space heating, space cooling, and ultimately power generation. This paper will present an overview of the present state of pond technology, describe some of the problems requiring further R&D, and suggest some likely IPH pond applications.

II. DESCRIPTION OF SOLAR PONDS

For purposes of description, solar ponds will be classified into three basic types: salt gradient ponds, shallow solar ponds, and innovative concepts. Further details on some of these are given in the references to another paper [3] in this Proceedings.

Salt Gradient Ponds

This is the concept which is usually denoted by the term "solar pond." A section of a salt gradient pond is shown in Figure 1. This type of pond has three distinct layers: the surface convecting layer, the non-convecting layer, and the bottom convecting storage layer. Solar radiation is absorbed both within the pond liquid and at the pond bottom, which is usually dark colored. The normal thermal convection pattern, where the warmer bottom liquid rises by buoyancy to lose its thermal energy at the surface, is suppressed by dissolving more salt at the bottom than at the top. This salt gradient offsets the thermal density gradient and prevents thermal convection. The non-convecting salt gradient layer acts as an insulator for the convecting layer at the bottom and also provides thermal storage. Usual pond depth ranges between about one and three meters. Under good operating conditions, the storage layer can reach nearly the boiling point (boiling is obviously undesirable due to its de-stabilizing effect) while the surface layer is at ambient air temperature or possibly slightly cooler, due to evaporation and/or night sky radiation. In fact, a pond can freeze over during winter and still supply useful heat from the storage layer, due to the temperature gradient through the pond (ice acutally helps pond performance by reducing convective and evaporative heat losses at the surface, while transmitting a substantial fraction of incident insolation).

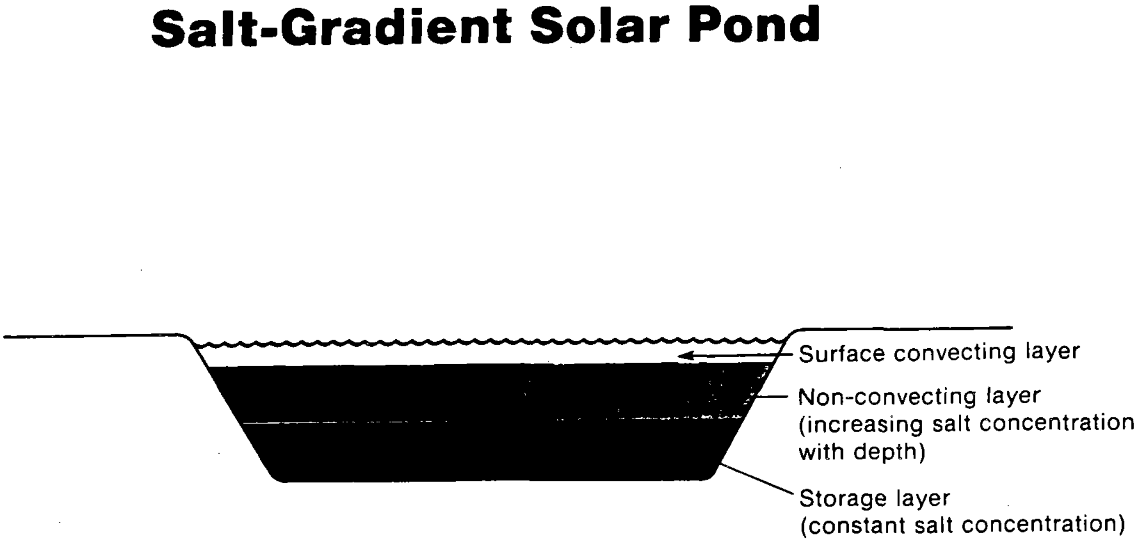

FIGURE 1. Cross Section of a Salt Gradient Pond

Starting up and maintaining a salt gradient pond is still something of an art. Multiple layers of brine of decreasing salinity must be carefully placed into the pond cavity, with a layer of fresh water at the surface. Salt diffusion will establish a continuous gradient through the convecting layer, but it will also eventually lead to a uniform salt density, thus nullifying the pond's ability to suppress convection. To counteract the salt diffusion, concentrated brine is periodically injected at the pond bottom and fresh water into the surface layer. This procedure, though necessary, requires fresh water and poses a potential salt pollution hazard. Another process requiring some engineering finesse is extraction of heat from the storage layer. An in-pond heat exchanger presents less risk of disturbing the gradient layer, but it is generally more efficient and economical to pump brine from the storage layer through an external heat exchanger. This must be done carefully so as not to create flow patterns that de-stabilize or erode the storage layer. The Israelis have developed a method for doing this, as well as extracting water from the surface convecting layer to cool the condenser of a turbine generator or absorption refrigeration machine, and then reinjecting it into the surface layer. This must also be done with care, since the top layer is relatively shallow and surface currents could erode the top of the gradient layer.

A novel approach to maintaining the salt gradient without the necessity of bottom brine injection and surface flushing is the saturated salt pond. This concept utilizes a salt for which the solubility increases greatly with temperature. The pond is kept saturated with salt at all levels, but since the pond is hotter at the bottom than at the top (once the pond is started up), more salt is dissolved toward the bottom. Thus, the temperature gradient maintains the salinity gradient, and vice versa. Since a saturated pond requires much more salt than an unsaturated one, it is essential that the salt be free or very cheap. In certain specified instances, this condition can be easily met. For example, the Dead Sea Postash Works in Israel annually discharges 10 million metric tons of calcium chloride and 30 million metric tons of magnesium chloride into the Dead Sea. A binary saturated solution of these salts is capable of raising the boiling point of water above 150°C [4], so that such a pond could supply energy close to 150°C for power generation or industrial heat.

Salt gradient ponds have significant economies of scale, both in construction and operation, although optimum pond size is not yet known. Pond excavation and plumbing costs per unit area decrease with pond size, and perimeter heat losses as a fraction of collected energy also go down as pond area increases. In general, ponds require waterproof liners, usually of rubber or plastic, to retain the brine, although in certain locations the soil is impervious enough that a liner is not needed. The liner and salt costs are two of the most important factors in pond initial costs.

Shallow Solar Ponds

The "shallow solar pond" (SSP) is not a pond in the usual sense of a hole in the ground with water in it, but is instead a large-area site built collector. It consists of a plastic water bag contained within an insulated enclosure, covered with a transparent glazing. A section of an SSP is shown in Figure 2. The SSP was developed by the solar energy group at Lawrence Livermore Laboratory to supply medium-temperature (40°C to 60°C) hot water in a batch mode for industrial processes [5, 6]. The pond is filled in the morning and the water allowed to heat during the day, then drained into an insulated storage tank for use.

SSPs are useful in areas where local climatic or soil conditions preclude the use of salt gradient ponds. Further, SSPs can be retrofitted onto large flat roofs, for example factory buildings, provided that the structure is adequate. SSPs are attractive for low-temperature IPH applications due to their low initial costs (estimated between $\$50/m^2$ and $\$100/m^2$). Drawbacks include significant performance decrease with temperature, and the necessity to replace plastic components more frequently than glass or metal.

Innovative Concepts

Several other pond concepts have been tested or proposed. These include:

Saltless Convecting Ponds. The non-convecting salt gradient layer is absent, and instead the deep pond is protected from thermal loss by transparent covers and/or night insulation [7, 8]. A diagram of this type of pond is shown in Figure 3. Possible covers and insulation include floating microglass beads, inflated multiple plastic film glazings, liquid foam, side and bottom insulation, or a closeable pond "lid," possibly with a reflector on the underside to increase insolation when the lid is open.

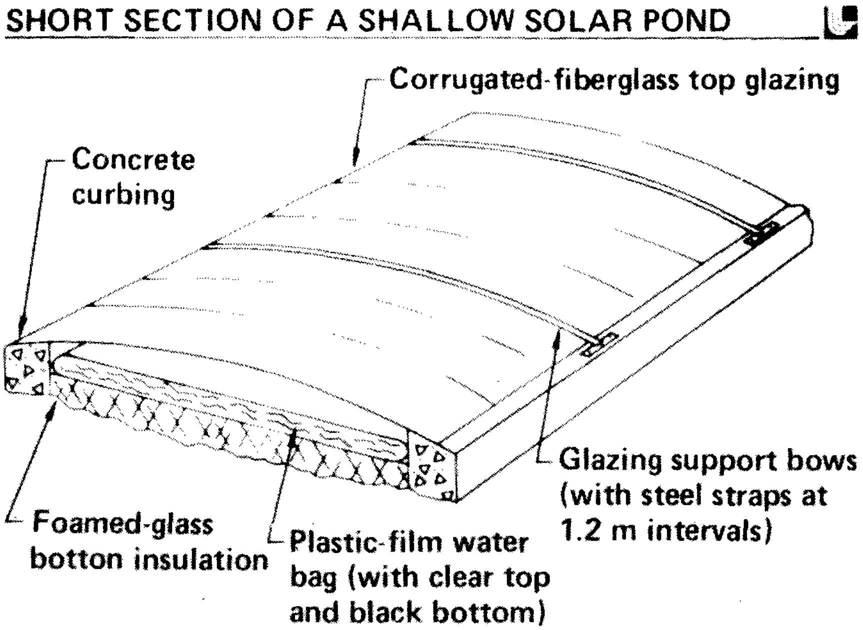

FIGURE 2. Shallow Solar Pond Cross Section

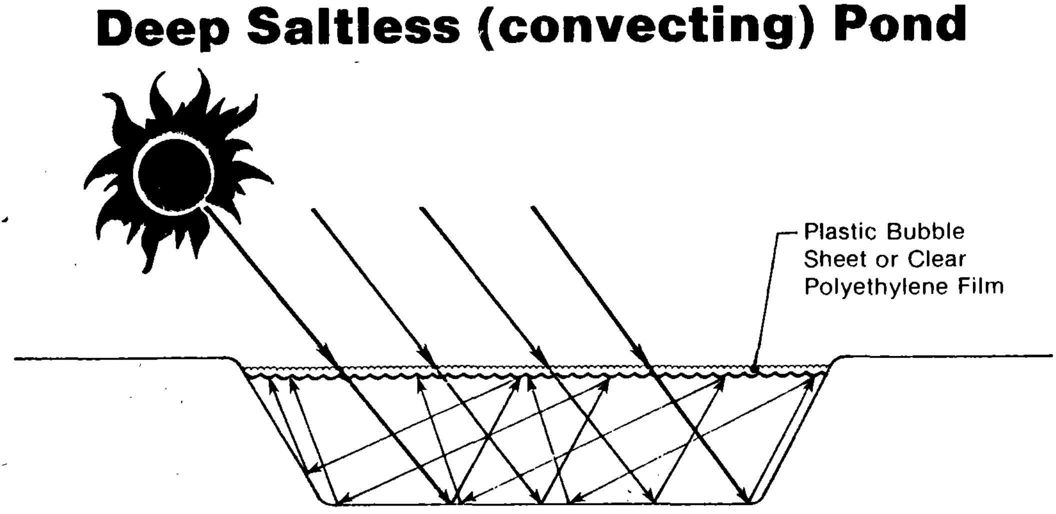

FIGURE 3. Diagram of Saltless Convecting Pond Concept

Gel and Viscosity Stabilized Ponds. Various substances added to water can increase the viscosity to the point where convection is suppressed, or where the entire pond gels to a semi-solid. Commercially available gelling and thickening agents have an unknown lifetime in the presence of solar radiation and other environmental effects. However, some experimental work has been done in the United States on viscosity stabilized ponds [9, 10]. Unless very cheap thickening and gelling agents become available, it is doubtful that these concepts can be economically competitive with salt gradient ponds.

Membrane Ponds. Transparent membranes can be inserted either horizontally or vertically into a pond to suppress convection. Horizontal membranes can be used to separate the non-convecting layer and the top and bottom convecting layers in a salt gradient pond, to prevent boundary migration. Multiple vertical membranes suppress convection in non-saline ponds by the same principle that honeycomb structures suppress air convection within flat-plate collectors [11]. As with the gel and viscosity stabilized ponds, it does not seem likely that these concepts will compete economically with salt ponds.

III. THE U.S. SOLAR POND PROGRAM

The objective of the U.S. solar pond program, under the U.S. Department of Energy, Office of Solar Applications is to establish ponds as a proven and cost-effective technology for providing low-temperature thermal energy for a variety of applications. The program started under the early ERDA solar effort, with the primary applications of interest being large-scale space heating and low-temperature IPH. As pond technology advances, higher temperature applications such as space cooling and thermal power generation will be explored.

Salt Gradient Pond Projects

Current U.S. salt gradient pond projects are summarized in Table I. Further descriptions of the individual projects are available [12, 13]. The Miamisburg pond deserves special recognition since it was paid for by the city of Miamisburg, Ohio, and DOE funding was used only to instrument the pond and take data. The pond cost \$35/m^2 (\$3.20/ft^2), which is projected to deliver heat at about 1.86 ¢/kWh (\$5.45/MBtu), based on an estimated ten-year pond life. This pond is the largest in the United States and is shown in Figure 4. The University of New Mexico experimental pond is shown in Figure 5.

Shallow Solar Pond Projects

Current and planned SSP projects are summarized in Table II. The first three projects are described in more detail by Casamajor [14]. The first two were never built due to unfavorable economics, but the Ft. Benning project is currently in the detailed design phase, and the estimated cost of \$95/m^2 is attractive to the Army, which cannot take fossil fuel costs as a tax deduction. An artist's conception of the project is shown in Figure 6; a more current layout has moved the ponds closer to the barracks and laundry to reduce heat losses in long piping runs.

TABLE I. Current Salt Gradient Pond Projects

Contractor/Loc.	Area	Depth	Key Objectives	Achievements/Problems
U. of NM Albuquerque	167 m^2	2.5 m	Gradient maintenance, heat extraction, stability with NaCl	Boiling temp reached; annual thermal efficiency only 8%, sloping walls give convection
Ohio State Univ. Columbus	200 m^2-old 450 m^2-new	2.5 m 2.5 m	Test boundary migration, stability, measure perimeter heat loss, test reflectors	Successful heat extraction, grain drying demonstration; wind blown debris reduced clarity
DOE Mound Lab Miamisburg, OH	2,000 m^2	3.0 m	Provide heat to city recreational building and swimming pool	Successful operation for one year; costs: \$35/m^2, \$5.45/MBtu (ten-year life)
Ohio AG R&D Center Wooster	155 m^2	3.0 m	Greenhouse heating, test cover and reflector, heat pump source	Chemical treatments developed to maintain clarity; leaks due to design and materials
Desert Research Inst. Boulder City, NV	10 m^2	1.0 m	Investigate feasibility of saturated ponds using $MgCl_2$, $CaCl_2$ and borax	Borax pond self-starting, demonstrated superior stability; algae problems, salt precipitation makes bottom white
Intertechnology Corp. Warrenton, VA	1 m^2	1-2 m	Lab-scale feasibility of saturated pond using sodium carbonate-bicarbonate salt	New project - no results yet

TABLE II. Shallow Solar Pond Projects

Project/Location	Area	Application	Status/Problems
Sohio Petroleum Co. Grants, NM	6 acres (Projected)	Uranium Ore Processing	Construction costs made system uneconomic; project currently on hold
Sweet Sue Kitchens Athens, AL	1,600 m^2 (Projected)	Chicken Packing	Potable water required HEX; small size made cost/unit area high; project cancelled by DOE
Ft. Benning, GA	25,600 m^2	Hot Water for Barracks and Laundry	2 million liters/day; est. cost \$95/m^2; detailed design by A/E in progress, start construction June 1980, finish December
Ft. Gordon August, GA	10,000 m^2	Barracks Hot Water	Rooftop ponds; preliminary design phase

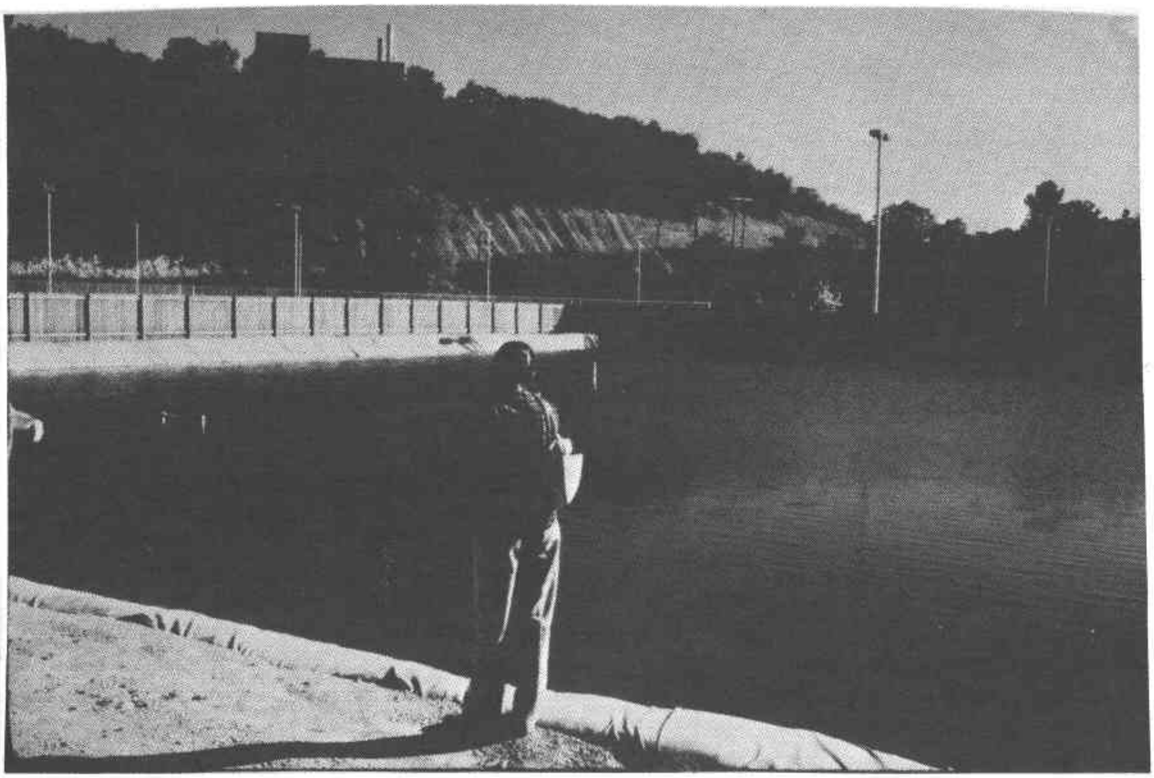

FIGURE 4. Miamisburg, Ohio – Salt Gradient Pond

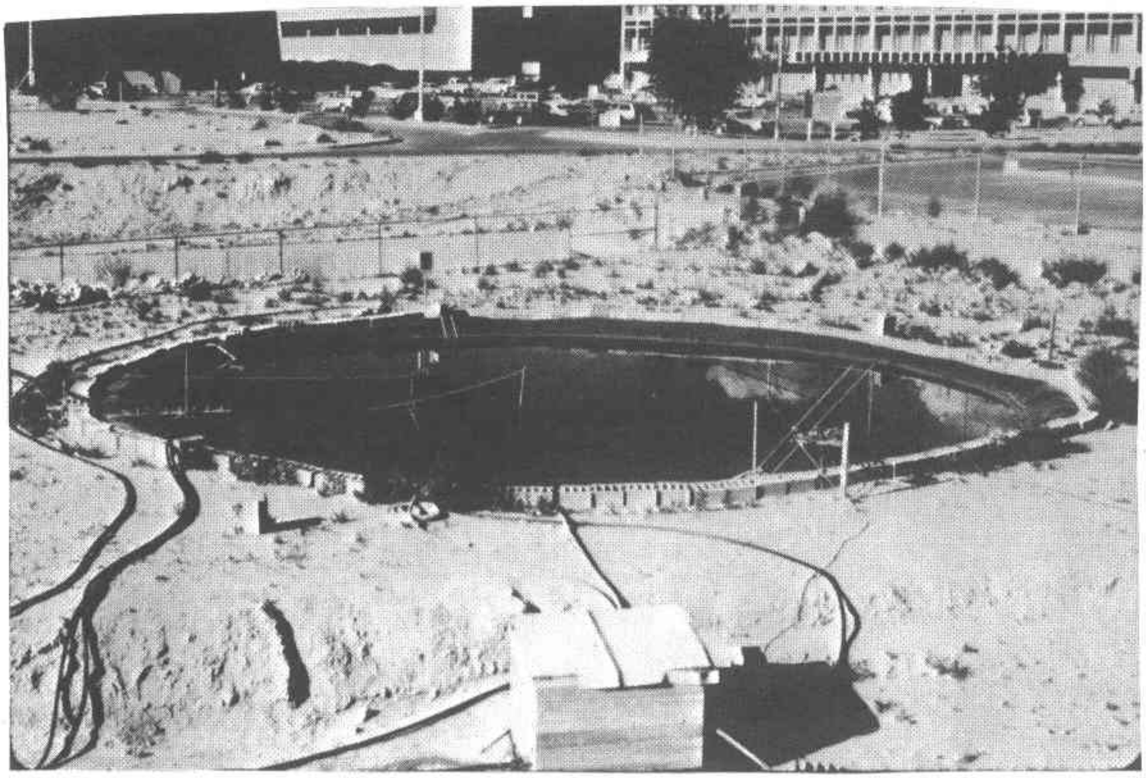

FIGURE 5. University of New Mexico Experimental Salt Gradient Pond

FIGURE 6. Artist's Conception of Ft. Benning Shallow Solar Pond Project

Innovative Pond Projects

Experimental and analytical investigations are being conducted at the Solar Energy Research Institute (SERI) on some of the innovative encepts using saltless ponds with transparent and/or movable insulation [7, 8]. The primary focus of the work is to develop workable pond concepts for areas where salt is expensive or not readily available, or where a salt pond would present unacceptable environmental problems. No work is currently underway in the United States on viscosity stabilized ponds. Membrane ponds are being investigated at Iowa State University [15].

Program Emphasis

The emphasis of the U.S. solar pond program is to resolve remaining technical problems, develop low-cost designs, and define optimum geographical areas and end-use applications. The major technical problems and solution approaches are outlined in Table III. The development of low-cost designs is an integral part of all the ongoing pond projects. A planned study to define optimum geographical areas and end-use applications is described in Section V.

TABLE III. Technical Problems and Approaches

Problem	Approaches
Prevent Convection	1. NaCl salt gradient 2. Other salt where cheap (e.g., bittern) 3. Saturated solutions (new research) 4. Gels (no promising candidates at present)
H_2O Clarity	1. Copper sulphate (for algae) 2. Chlorine (for bacteria) 3. Selective precipitation for minerals 4. Fences for debris
Heat Extraction	1. Optimize hot brine withdrawal for large ponds
Slow Migration of Layer Boundaries	1. Model pond and full-scale experiments 2. Theoretical hydrodynamic studies
Wind Driven Instabilities	1. Wave breaks may prove adequate 2. Problem needs theoretical hydrodynamic study
Scale Up to Many Acre Pond for IPH or Electricity	1. Field experiments including design studies
Salt Pollution	1. Liners for small ponds 2. Natural saline environment or impervious soil for large ponds
Pond Lifetime	1. Test and develop improved materials

IV. THE ISRAELI SOLAR POND PROGRAM

Israel began development of solar ponds in the late 1950s, primarily for power generation, under the leadership of Dr. Harry Tabor and his group at the National Physical Laboratory of Israel [16, 17, 18]. Israel's first experimental solar pond was constructed at the Dead Sea, utilizing concentrated $MgCl_2$ brine, a waste product of the Dead Sea Potash Works. The technical feasibility of the concept was proven when the temperature of the 600 m^2 pond reached 96°C. Two more ponds were constructed in Israel in 1960, and work continued until the mid-1960s, when a change of government combined with the availability of cheap oil caused a cutoff of pond funding. Work was resumed after the 1973 oil embargo and Israel, building on its earlier experience, is currently the world's leader in salt gradient pond development.

Four ponds have been built in Israel, with a combination of government and private funding since the program was revived. These are:

Dea Sea Potash Works. Near Sdom, 1,100 m^2 area. During its one year of operation the pond reached a maximum temperature of 103°C (above the boiling point of fresh water at the Dead Sea elevation). Successful heat extraction experiments were carried out, and the pond operated at an annual average collection efficiency of 15%.

Eilat. On the Red Sea, 1,100 m^2 area. This is a pilot project for a planned 100,000 m^2 pond to be used as a heat source for a multistage desalination plant. The pond reached the design temperature of 82°C.

Ormat Turbines Company. Yavne (south of Tel Aviv), 1,400 m^2 area. This pond, shown in Figure 7, supplies hot brine from the storage layer continuously at 90°C to the boiler of an organic Rankine-cycle turbine. Cool water at 29°C from the surface layer cools the condenser. The turbine produces 6 kW, of which approximately 20% goes to parasitic pumping power. The pond has been operating successfully for over a year, producing electrical power on a 24-hour basis.

Ein Bokek. On the Dead Sea, 6,400 m^2. This pond shown in Figure 8, is the world's largest. It was completed in the late summer of 1978 and has reached a temperature of 88°C. A 25 kW turbine has been operated from the pond, which will soon be replaced by a 300 kW turbine. This turbine size is designed to operate continuously off a 100,000 m^2 pond, but will be operated at the Ein Bokek pond at 150 kW capacity on an intermittent basis. The surface water quantity is inadequate for condenser cooling, so a cooling tower is being constructed for supplemental cooling. Further experiments for desalination and absorption air conditioning are planned for this pond. The pond is intended to supply electricity and/or cooling to a resort hotel at the conclusion of tests.

Future Program

The primary focus of the Israeli pond program is large-scale baseload electricity generation, utilizing ponds at the Dead Sea where brine is essentially free and land is available. The next step after the Ein Bokek tests is a 100,000 m^2 (25 acre) pond driving a 300 kW turbine scheduled for 1980 to 1981. This will be followed by a 1 km^2 pond (250 acres) with a 5 MW turbine, planned for 1982 and after. The Israelis see the 1 km^2 pond/5 MW turbine combination as a basic pond electrical generation module. The Israeli pond budget for 1979 to 1982 totals $12 million. Secondary pond applications of interest are desalination, absorption cooling, and IPH.

V. U.S./ISRAEL COOPERATIVE POND PROJECTS

In late 1978, representatives of the U.S. Department of Energy and the Israeli Ministry of Energy and Infrastructure (MOEI) met in Tel Aviv to discuss cooperation in the field of solar energy, and concluded that joint projects would be beneficial to the solar energy program of both countries, particularly in the specific areas of solar ponds, advanced photovoltaic research, passive and active cooling, and biomass conversion. Preliminary Project Proposals were exchanged early in 1979, and in September 1979, a U.S. delegation consisting of DOE, USDA, and SERI personnel met with MOEI representatives in Jerusalem to draft an overall cooperative agreement and specific project descriptions. The agreement is expected to take effect approximately January 1, 1980, and extend for four years.

Four pond projects were agreed to at the September meeting:

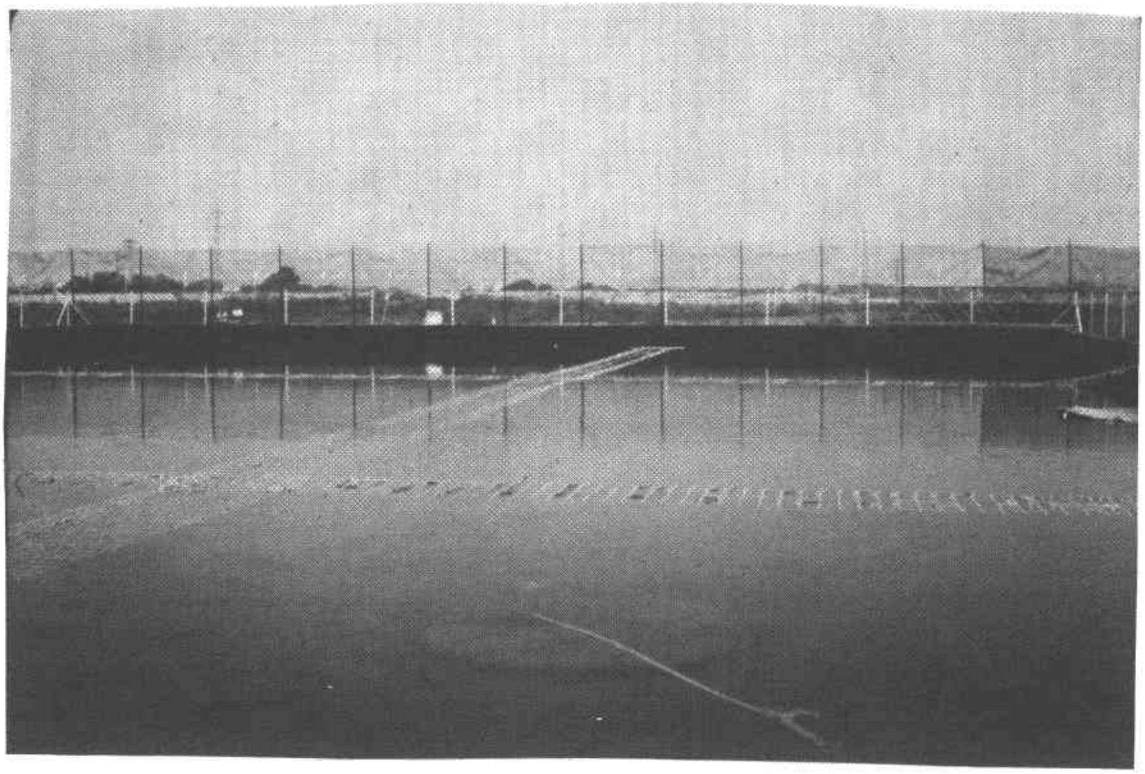

FIGURE 7. Experimental Pond at Yavne, Israel

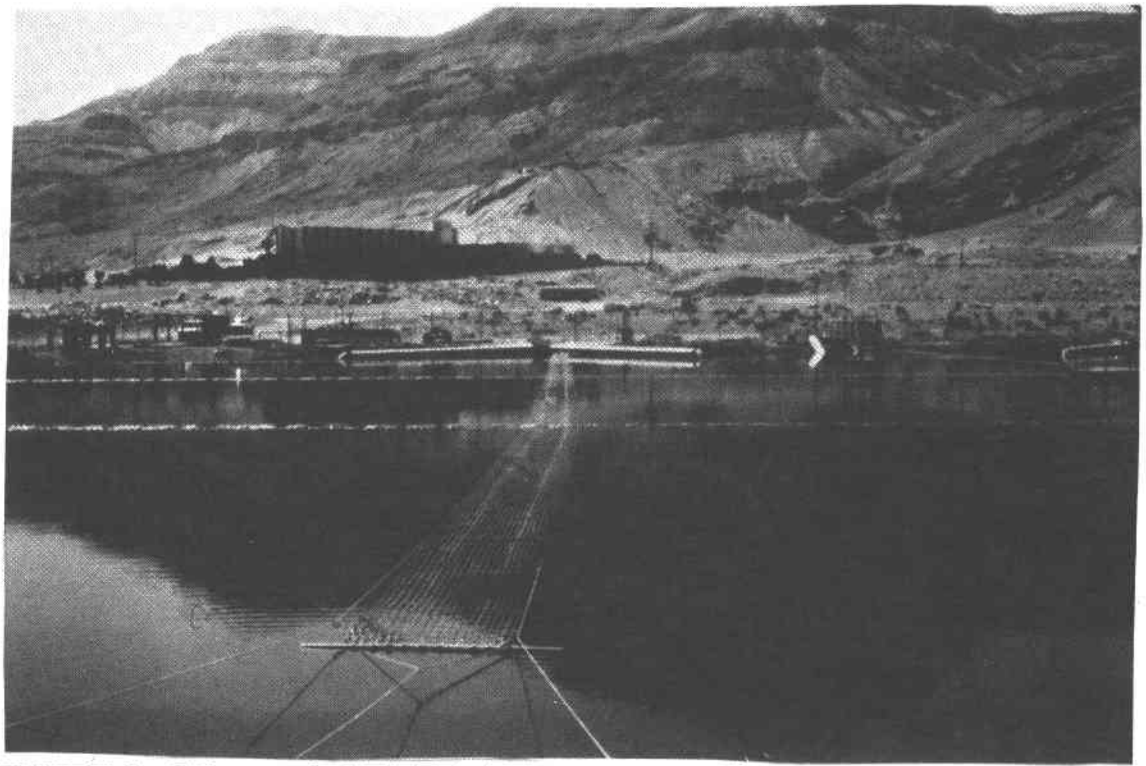

FIGURE 8. Solar pond at Ein Bokek, on the Dead Sea in Israel. A resort hotel in the background will eventually be provided with electricity and/or cooling from the pond.

U.S. Pond Regional Applicability Study. This project will start in early 1980 and run for approximately nine months, with funding provided by the United States and participation by Israeli investigators. The purpose of the study is to define optimum geographical areas and end-use applications for ponds, including consideration of such factors as insolation; wind; ambient temperatures; soil conditions; availability of land, salt, and water; proximity of appropriate end-use applications; required end-use temperature, and other factors. The study will result in a report which will assist DOE in planning the U.S. pond program.

Coordinated Pond Field Testing. This jointly-founded project will commence in FY81 and continue for three years. A coordinated series of field tests will be undertaken in the two countries, with exchange of data. Israeli tests will concentrate on large (up to 1 km^2) ponds for electrical generation. Field tests of ponds in the United States are expected to be smaller and to aim at a variety of applications, such as space heating, space cooling and IPH.

Saturated Pond Research. This project will run from FY80 through FY82 and receive joint funding. Coordinated research will be carried out in both countries to determine the performance of salts and materials for use in saturated ponds. Data and materials will be exchanged. One or more prototype ponds will be constructed in each country, brought to operating temperature, and monitored for at least one year to determine performance under actual or simulated operating conditions.

International Market Study. This jointly funded project will take place during FY82, with participation by investigators from both countries. The study will determine marketing opportunities for ponds, both saturated and non-saturated. Promising matches of optimum physical conditions with appropriate applications in developing and developed countries will be identified.

An existing U.S./Israel pond project which is not under the scope of the cooperative agreement involves a feasibility study of converting a portion of Salton Sea into a number of large salt gradient ponds for baseload power generation. This project is currently funded jointly by Southern California Edison, the California Energy Commission and Ormat Turbines of Israel. It is expected that the project will be expanded, with participation by Jet Propulsion Laboratory and funding by DOE. It has been recommended that this project be brought within the scope of the U.S./Israel cooperative program in order to ensure technical and programmatic coordination.

The U.S./Israel cooperative pond projects should serve to advance the pond programs of both countries. The addition of U.S. funds to the Israeli pond budget will permit Israel to accelerate their large pond field tests. Likewise, the U.S. program will be advanced by access of U.S. investigators to Israeli data, experience and expertise.

VI. POND APPLICATIONS TO INDUSTRIAL PROCESS HEAT

General Considerations

Solar ponds, especially the salt gradient variety, are a very promising solar technology due to their potentially low cost and their ability to supply low-temperature heat for a variety of applications. Low-temperature IPH is a natural application for early pond utilization, under the right conditions. Ponds have certain inherent constraints on their use, some of which are:

- cheap land availability;
- water or brine availability;
- free or cheap salt;
- low-temperature application;
- salt pollution;
- appropriate soil conditions: permeability, conductivity, water table, organic matter;
- meteorological conditions: insolation, wind, ambient temperature; and
- local topography.

Industrial Process Heat Applications

Any low-temperature IPH application which is compatible with the above constraints can effectively use ponds as a heat source. In addition, ponds may well be cost-effective as pre-heaters for higher temperature IPH applications. Some low-temperature applications with early potential for pond utilization include:

Salt and Minerals Production. Some salt and minerals are currently produced by concentrating brine in evaporation pans. This process can be accelerated by the use of heat from ponds. In addition, bittern (concentrated brine) is available as a waste product at zero or negative cost, and this can be used to maintain the pond salt gradient.

Petrochemicals Storage. Petrochemicals are stored in wells in some locations, and must be heated in order to be pumped to the surface. The low-temperature heat can be supplied by ponds.

Agricultural Drying. A pond is an ideal heat source for agricultural drying, which usually takes place in the fall. The pond will heat up during the summer, and reach its maximum temperature at about harvesting time. The stored heat can then be extracted through a heat exchanger for crop drying. The seasonal storage aspect of ponds smooths out daily insolation variations, and gives them a significant advantage over other solar drying methods. The pond could also be used for other applications the rest of the year.

Hot Water Production. A multitude of industries use hot water, especially food processing, food container washing, laundries, metal plating, dairies, etc. Ponds can provide a dependable and predictable flow of hot water for such applications.

Industrial Drying. Ponds can supply hot air, via a heat exchanger, for drying of laundry, processed foods, painted surfaces, textiles, etc.

Costs

Due to the lack of performance and economic data on ponds, it is difficult at this time to make precise predictions of energy costs from ponds. The projected initial costs of $\$95/m^2$ for SSPs (Ft. Benning project) and $\$35/m^2$ for salt gradient ponds (Miamisburg pond) makes them much cheaper than concentrating collectors, particularly since salt gradient ponds have built-in storage.

In a companion paper in these Proceedings, Brown, et al., [19], compute the levelized cost of energy delivered by ponds for a metal can washing process and for a commercial laundry. Delivered energy costs range between about \$5/GJ and \$12/GJ (approximately \$5/MBtu to \$12/MBtu), depending on rate of return, salt cost, assumed fuel escalation rate, and other factors. This is in general agreement with the projected energy cost of \$5.45/MBtu for the Miamisburg pond. In particular, this study shows that ponds produce significantly cheaper energy than parabolic troughs for these applications. The paper's conclusion is that salt gradient ponds achieve economic viability for IPH when conventional fuel prices are about \$5/MBtu and are expected to increase at 10% per year. Ponds are far more cost-effective than any other solar IPH technology for the applications studied.

VII. CONCLUSIONS

Ponds are a solar technology with significant potential for producing very cost-effective low-temperature thermal energy for many applications. While some technical problems remain to be solved, the basic technical and economic feasibility of ponds has been demonstrated both in the United States and abroad. The development of solar ponds should be vigorously pursued in the U.S. solar energy program, and it would be a serious mistake if ponds were not included in the solar IPH program.

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REFERENCES

1. D'Alessandro, Bill, "Let a Hundred Flowers Bloom," Solar Age, Vol. 4, No. 8, August 1979, pp. 6-9.
2. Treadwell, G. W., "Parabolic Trough/Flat-Plate Collector Comparison, paper included in the Proceedings.
3. Ochs, T. L. and J. O. Bradley, "Low-Temperature Industrial Process Heat from Non-Convecting Solar Ponds," paper included in this Proceedings.

4. Melamed, Abraham, President, Tushia Consulting Engineers, Givatayim, Israel, personal communication, 1979.

5. Dickinson, W. C., A. F. Clark and A. Iantuono, Shallow Solar Ponds for Industrial Process Heat: The ERDA-Sohio Project, Lawrence Livermore Laboratory, Report UCRL-78288, 1976.

6. Casamajor, A. B. and R. E. Parsons, Design Guide for Shallow Solar Ponds, Lawrence Livermore Laboratory, Report UCRL-52385, 1978.

7. Jayadev, T. S., Michael Edesess and Jon Henderson, "Solar Pond Concepts: Old and New," paper presented at the 14th Intersociety Energy Conversion Engineering Conference, Boston, August 5-10, 1979, SERI/TP-35-213.

8. Edesess, Michael et al., "Economic and Performance Comparisons of Salty and Saltless Solar Ponds," paper presented at the 14th Intersociety Energy Engineering Conference, Boston, August 5-10, 1979, SERI/TP-35-213.

9. Shaffer, Lloyd H. (deceased), "Viscosity Stabilized Solar Pond," U.S. Patent 4,138,992, filed July 21, 1975.

10. Shaffer, Lloyd H., "Viscosity Stabilized Solar Ponds," Proceedings of the International Solar Energy Society, Congress, New Delhi, January 1978.

11. Hollands, K. G. T., "Honeycomb Devices in Flat-Plate Collectors," Solar Energy, Vol. 9, p. 159, 1965.

12. Proceedings of the Third Annual Solar Heating and Cooling Research and Development Branch Contractor's Meeting, September 24-27, 1978, Washington, D.C. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, Stock No. 061-000-00265-1.

13. Solar Heating and Cooling Research and Development Project Summaries, U.S. Department of Energy, Division of Solar Applications, May 1979. Available from the U.S. Government Printing Office, Stock No. 061-000-00072-1.

14. Casamajor, Alan B., "The Application of Shallow Solar Ponds for Industrial Process Heat: Case Histories," paper W-II-B-3, Proceedings of the 1979 Congress of the ISES, Atlanta, Georgia, May 28 to June 1, p. 259. Also available in expanded form as Lawrence Livermore Laboratory reprint UCRL-81-704, October 16, 1978.

15. Hull, John R., "Membrane Stratified Solar Ponds," Abstract M-IV-C-1, Proceedings of the 1979 ISES Congress, Atlanta, May 28 to June 1, p. 79.

16. Tabor, H., "Solar Ponds: Large Area Collectors for Power Production," Solar Energy, Vol. 7, No. 4, pp. 189-194, 1963.

17. Weinberger, Herschel, "The Physics of the Solar Pond," Solar Energy, Vol. 8, No. 2, pp. 45-56, 1964.

18. Tabor, H. and R. Matz, "A Status Report on Solar Pond Projects," Solar Energy, Vol. 9, No. 4, pp. 177-182, 1965.

19. Brown, K. C., M. Edesses and T. S. Jayadev, "Solar Ponds for Industrial Process Heat," paper included in this Proceedings.

Question asked during presentation: Won't solar ponds emit a lot of steam and ground fog in the winter.

Answer: This could happen, but it is not likely. Conventional lakes cause mist and ground fog because the surface is significantly warmer than the air. Due to the temperature gradient through the pond, the surface temperature should not exceed ambient temperature by very much. As pointed out in the paper, the pond surface can freeze without greatly degrading the pond performance, and this would prevent ground fog formation.

TECHNOLOGY ASSESSMENT: LINE-FOCUS CONCENTRATORS

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Introduction

Over the past five years, collector/system hardware experiences at Sandia Laboratories within the Solar Thermal Power Systems Program sponsored by the DOE Office of Energy Technology have been the following (Reference 1):

Linear Fixed Mirror, Movable Receiver Concentrator - GA
Linear Fresnel Lens Concentrator on Two Axis Tracker - MDAC
Parabolic Dish - Raytheon
Linear Fixed Receiver, Movable Mirror Concentrator - Suntec
Parabolic Trough - Hexcel
Linear Fixed Mirror, Movable Receiver Concentrator - SA
Parabolic Trough - Del
Moving Belt Fresnel Mirror Concentrator - FMC
Parabolic Trough - Acurex
Parabolic Trough - Sandia
MSSTF - 8000 Ft^2 Collectors, 32 kW_e Total Energy Plant
Willard - 14,000 Ft^2 Collectors, 25 HP Irrigation Plant

These eleven collectors and two systems were fabricated, tested, and evaluated in order to define engineering development problems requiring solution prior to commercialization initiatives. This paper describes the major engineering problems and near-term development emphasis.

Summary Status of Existing Technology

From an overall viewpoint the status of existing line-focus collector technology can be summarized by the following three points.

First, the thermal efficiencies of current collectors are not yet at the goal of between 60 and 70% at 600°F although there appears a definite and encouraging trend with successive collector generations to meet this goal.

Second, the durability of existing collectors is low relative to requirements of 10 to 20 years dictated by economics. Both environmental degradation of materials and, as yet, inadequate treatment of system safeties contribute to this durability issue.

Third, existing technology does not yet lend itself to low-labor mass-production materials and processes which will be required to meet cost goals.

Collector Concept

The performance prototype concepts which have been evaluated at Sandia Laboratories include the tracking aperture type exemplified by the parabolic trough and the fixed aperture type exemplified by the Solar Linear Array Thermal System, the Fixed-Mirror Solar Collector, and the Faceted Fixed-Mirror Concentrator.

Utilizing measured normal-incidence thermal efficiencies, an estimate of annual average collector efficiency can be made which includes cosine losses. The results shown in Figure 1 as a function of average collector temperature indicate a substantial performance advantage to the tracking aperture type of collector mainly due to the lower average cosine losses relative to the fixed aperture type of collector.

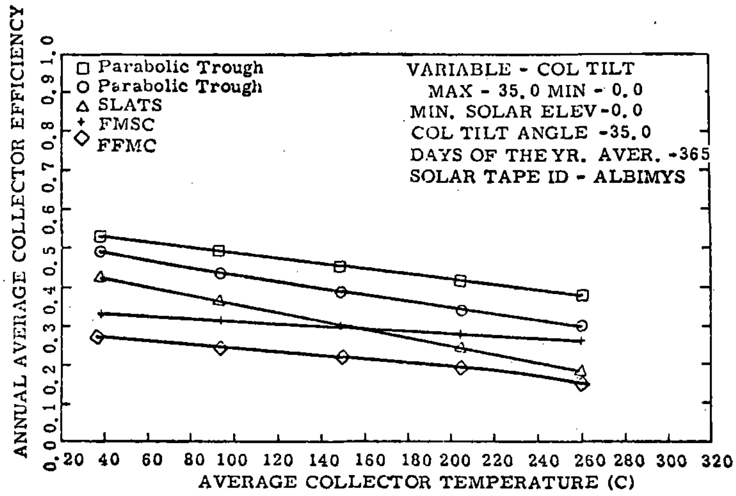

FIGURE 1. ESTIMATED AVERAGE COLLECTOR EFFICIENCY BASED ON MEASURED NORMAL - INCIDENCE EFFICIENCIES.

This performance advantage of the tracking aperture over the fixed aperture is a primary consideration to both near-term and longer-term applications of line-focus collectors. (Reference 2).

In the near-term, process heat is the likely application market because of system simplicity. Since approximately half of the process heat usage is below 600^{O}F, it is important, during market initiation, to identify a collector concept which is capable of giving high performance over this potential temperature-use spectrum.

In the longer-term, cogeneration which will obtain process heat from a power conversion cycle is the likely application market because of economic advantages of simultaneous production of electricity and process heat. In this case, it is important to identify a collector concept which is capable of high performance at elevated temperatures in order to provide high quality energy to the power conversion cycle to achieve reasonable thermal-to-electric conversion efficiencies.

Test and evaluation data to date indicate that the parabolic trough is the preferred line-focus collector concept for the near-term and longer-term potential markets.

Recent engineering development efforts at Sandia Laboratories have resulted in a parabolic trough collector which establishes the feasibility of meeting the thermal efficiency goal. Test data for the so-called Engineering Prototype Trough (References 3, 4) indicates 60% peak-noontime thermal efficiency at 600°F. To achieve the performance goal this collector embodies, as described in this paper, several design improvements in the areas of reflector material, structure, tracker, receiver and selective coating.

Structures

In order to achieve cost-effectiveness in mass-production, not only must the collector structure feature a high stiffness-to-weight ratio so as to keep material content to a minimum but also the collector structure must be amenable to low-labor manufacturing processes. Three structural concepts with high stiffness-to-weight ratios and potential for mass-production manufacturability are shown in Figure 2. Structural design analyses indicate for a 90 mph wind survival criterion that these concepts may weigh three to four pounds per square foot including mirrored glass which serves as the reflector.

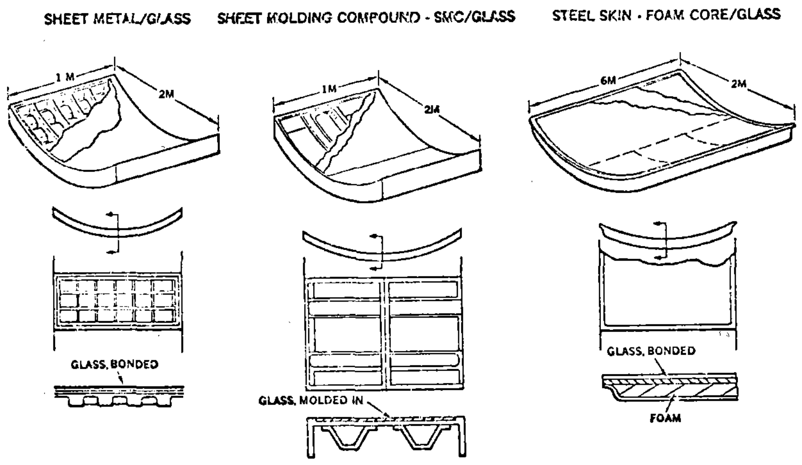

FIGURE 2. PARABOLIC TROUGH REFLECTOR/STRUCTURE DESIGN CONCEPTS.

The first concept consists of a ribbed frame panel which is stamped from sheet metal and attached to a sheet metal skin supporting the reflector.

The second concept consists of a sheet molding compound (SMC) panel into which is molded the glass reflector to eliminate a separate bonding operation; hat sections are bonded to the panel to achieve high stiffness. The 2m x 1m dimensions of the sheet metal and SMC structures are constrained by current stamping and molding press capabilities in industry.

The Budd Company has recently initiated efforts to develop prototypes of the sheet metal and SMC concepts.

The third concept consists of a sandwich structure of high density foam core and steel skins in a size potentially as large as 2m x 6m.

Reflective Materials

Over the past several years at Sandia Laboratories accelerated environmental testing of materials has been performed (Reference 5). Anodized aluminum after one year of freeze/thaw cycling in a high humidity environment estimated to simulate twelve years of real time exposure shows severe corrosion of the material which significantly degrades reflectance.

Similarly, a variety of polymer film reflective materials have been tested including aluminized acrylic. After accelerated aging the material shows severe delamination occurring between the film and the structure which significantly reduces optical performance and, more importantly, lifetime. Lifetime of typical polymer films is further limited due to poor abrasion resistance of the film.

Based on environmental test data to date, mirrored glass appears to be a preferred reflector material for at least the near-term. Its advantages over alternative materials are twofold. First, specular reflectivity of 95% has been achieved with silvered glass as contrasted to only about 75% with anodized aluminum and about 85% with polymer films. Second, as supported by environmental testing, mirrored glass gives significantly better durability.

Development of mirrored glass for line-focus collectors has been slow for the following reasons: alternative materials are currently less expensive, glass is more difficult to design into a collector due to a long-term tensile stress limitation of about 1000 psi, and, finally, production sources have been unavailable.

Three potential concepts for glass are chemically strengthened, thermally formed, and, socalled, thin glass laminates. Development problems and issues with these concepts are listed in Figure 3.

Chemical strengthening, achieved by an ion exchange process, provides a high compressive stress state at the surface of the glass sheet. Thus, chemically strengthened glass can be elastically deformed into the collector to form the reflector surface. Corning Glass Company has initiated an effort to estimate cost of chemically strengthened glass in production volumes.

Thermal forming of automotive windshields is accomplished either by gravity sagging into a frame mold or press forming between male-female surface molds. Ford Glass Division using gravity sagging and PPG using press forming have initiated efforts to develop thermally formed glass prototypes of 1m x 1m dimensions. A key problem which has not yet been addressed is the silvering of large, contoured surfaces.

Thin glass laminates consist of perhaps a 10 mil mirrored glass sheet bonded to sheet steel. The neutral axis can be placed in the steel allowing the glass to remain in compression when elastically deformed. Because of the fragility of the thin glass between forming and lamination, manufacturability has been of serious concern.

CHEMICALLY STRENGTHENED: (50 MIL x 45 IN. x 40 IN.)	o PRODUCTION COST - CORNING o LONG TERM DURABILITY IN STRESSED STATE
THERMALLY FORMED: (60 MIL x 45 IN. x 40 IN.)	o PRODUCTION COST o CONTOUR TOLERANCES AND HANDLING - FORD GLASS DIVISION AND PPG o MIRRORING OF CURVED PIECES
LAMINATED: (10 MIL x 45 IN. x 40 IN.)	o PRODUCTION COST o MANUFACTURABILITY o LONG TERM DURABILITY IN STRESSED STATE o HANDLING THROUGHOUT MANUFACTURING

FIGURE 3. DEVELOPMENT PROBLEMS/ISSUES FOR GLASS AS A REFLECTIVE MATERIAL.

Receiver

Because of an apparent near-term cost advantage, current emphasis is on receivers which are sealed to the environment but non-evacuated.

Studies have indicated a significant performance advantage of 10% increase in thermal efficiency for the evacuated receiver but requires a laboratory type vacuum (References 6, 7, 8). Furthermore, accounting for thermal expansion in an evacuated receiver is a difficult design problem within a cost budget of about seven dollars per linear foot of receiver. A definite advantage of the evacuated receiver is that the cleaning problem of the receiver interior is eliminated.

In addition, an antireflection coating on both the interior and exterior surfaces of the receiver glass envelope appears from analysis to offer a significant performance advantage of 10% increase in thermal efficiency. Corning Glass Company has recently initiated an effort to develop a prototype glass envelope with an antireflection coating for test and evaluation at Sandia Laboratories. Both cost and durability due to environmental degradation are issues of concern for antireflection coatings.

It may be of interest, before leaving the topic of reflectors and receivers, to note a phenomenon which has been observed on several collectors. Discrete focal lines are seen on the receiver tube giving an appearance of light and dark stripes. Laser ray trace data confirms that the phenomena is a characteristic of the reflector. The effect has now been seen on the Acurex trough with either anodized aluminum or thin glass laminate, the Solar Kinetics trough with aluminized acrylic, the Custom Engineering trough with sagged glass, and the Sandia trough with chemically strengthened glass. Thermal analysis indicates a one percent efficiency degradation from the effect; of more concern may be the influence of the effect on performance of a photovoltaic receiver which requires more uniform illumination.

Selective Coatings

In order to achieve reasonable efficiencies at elevated temperatures, an external receiver in a line-focus collector must feature a selective coating. Such coatings maximize absorptance in the visible spectrum and suppress radiation in the infrared spectrum. Black chrome has been the most popular selective coating for line-focus collectors as well as flat plate collectors.

A thermal instability has been previously noted from typical black chrome plating baths in which solar absorptance is significantly reduced after only a few hundred hours at temperature (Reference 9).

It appears that current emphasis will remain with black chrome as a selective coating. It should be noted that SERI has recently initiated efforts to develop black cobalt as a selective coating.

Based on work over the past two years at Sandia Laboratories in cooperation with Harshaw Chemical Company, thermal stability of black chrome has been achieved in the laboratory using a modified plating bath composition.

Two efforts over the past year are being used to formulate a plating process definition. Honeywell has produced a preliminary draft of a plating handbook which relates optical properties to bath composition and plating parameters. Sandia in conjunction with Highland Plating has recently completed a production run of black chrome plating to investigate production process problems. It appears that typical production plating instrumentation may be inadequate to achieve at this time a specification for high quality selective coatings (Reference 4).

Trackers

Sun-tracking by means of the shadow band detector has been the popular method of providing the tracking function. Using sun-tracking, the average high intensity point in the sky is tracked. Problems to date include poor tracking accuracy, false locks on clouds or buildings, biases due to selective drifting of differential amplifiers, and maintenance due to dirt accumulation.

In addition to sun-tracking, there are two other methods of tracking: computer-tracking and aperture-tracking. Using computer-tracking the sun's theoretical position is computed based on a clock input; the collector can then be pointed to the computed angle using feedback from a position sensor. Using aperture-tracking the collector is positioned to maximize the flux on the receiver by means of a flux sensing device.

Current emphasis in tracking is directed (Reference 10) toward combining computer-tracking and aperture-tracking as shown in Figure 4. A search algorithm is periodically initiated to correct computer-tracking biases by means of aperture-tracking. Furthermore, aperture-tracking serves to integrate the flux distribution down the length of the receiver to find the best average position for the collector drive string.

A fine resistance wire, helically wrapped down the receiver, is being investigated as a fast responding flux sensor. Flux sensing based on fluid temperature appears to be too slow in response due to the relatively large thermal mass involved.

The key problem at this time appears to be identification of a collector position indicator giving tenth degree accuracy at a cost of only a few hundred dollars.

If microprocessors are utilized to support the tracking function, it is suggested that a process computer should be designed to integrate the tracking function, the fluid control function and the systems safeties.

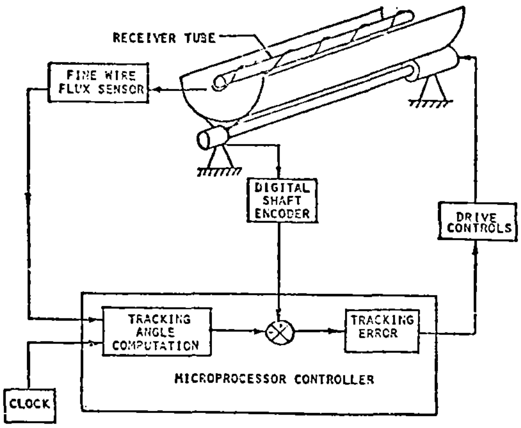

FIGURE 4. TRACKER BASED ON COMBINATION OF COMPUTER-TRACKING AND APERTURE-TRACKING.

Drive

Current emphasis in the drive system is the concept of an integral drive pylon which consists of an electrically driven pump interfacing with a hydraulic pressure accumulator and a hydraulic actuator to rotate the collector drive string. Several advantages can be listed for this concept: field layout only requires electrical wiring, high force capability at low speed, low instantaneous power requirement, and multiple speed capability with little additional cost. Perhaps the key advantage results from the emergency defocus requirement. The hydraulic accumulator in operation remains pressurized at all times; in an emergency stow condition the accumulator is dumped to drive the collectors to stow. Electromechanical drive systems must provide standby generator power or batteries both of which are subject to reliability problems. Design of a gearbox specifically for an electromechanical drive system is a key area requiring engineering development.

Wind Loads/Foundations

A consistent problem with existing solar collector installations has been high cost associated with pylons and foundations. Two recently completed test programs indicate that designs have been very conservative.

Wind loads on parabolic trough arrays have been measured by Colorado State University (Reference 11). Results indicate that fences combined with row-to-row shadowing cause reductions of peak lift and lateral forces by factors of two and four respectively. No significant reduction in pitching moment was observed by CSU indicating that reflector structure design has been adequate using previous wind loads. Finally, the test data indicates that mounting height of the collectors from the ground should be as small as possible to minimize wind loads and thereby reduce structural weight and cost.

A foundation design study and test program has been conducted by Higgins, Auld, and Associates (References 12, 13, 14). Results of the design study indicate that cylindrical reinforced concrete piers provide the most cost-effective foundation system of fifteen designs considered. Test data verified that restraining forces provided by the soil are substantial and should be accounted for in the foundation design at sites featuring good soil properties. This foundation work indicates that a goal of fifty cents per square foot of collector aperture for foundations may be feasible.

Collector Field Subsystem Layout

Two other consistent problems with existing solar collector systems have been high cost of the piping and high thermal losses in the field piping.

An ongoing field layout design study by Jacobs-Del Engineering has reached a number of preliminary conclusions. Unlike refinery type systems which run under steady state conditions, solar systems experience high thermal losses due to night cooldown; it appears that increased insulation is cost-effective in decreasing thermal losses. Furthermore, downsized piping to further reduce heat losses and thermal mass appears overall cost-effective even though cost of parasitic pumping may increase. Finally, and perhaps most importantly, the study indicates that a piping cost goal of twenty percent of installed field cost may be feasible.

State-of-The-Art Trough Design Features

Figure 5 summarizes suggested trough design features. A thermal efficiency goal of greater than 60% at 600°F requires a system error budget of seven milliradians which implies accurate structures with two milliradian slope error. Dimensions such as two meter aperture, 92° rim angle and six meter module length are suggested in order to begin some standardization to stimulate production oriented sources for structures and reflector materials during market initiation. Modular systems based on 50,000 square feet of collectors may be appropriate to attract user interest during market initiation but it is suggested that such modules be designed to be expandable to larger installations in the longer-term. Likewise, fluid control systems can be simple in concept for say 300°F process heat utilizing collectors capable of 600°F, however, cogeneration systems will require more accurate temperature controllers.

- SYSTEM ERROR BUDGET = 7 MR.
- 2 METER APERTURE, 92° RIM ANGLE, 6 METER COLLECTOR MODULE LENGTH
- 24 METER DRIVE STRING LENGTH WITH CENTER DRIVE
- 4608 SQUARE METERS FIELD MODULE EXPANDIBLE TO 46080 SQUARE METERS
- INTEGRAL DRIVE PYLONG WITH ELECTRIC PUMP/HYDRAULIC ACCUMULATOR AND ACTUATOR
- SEALED/UNEVACUATED RECEIVER WITH BLACK CHROME SELECTIVE COATING AND OIL HEAT TRANSFER FLUID
- MICROPROCESSOR BASED TRACKER WITH CLOSED LOOP INTEGRATING FLUX SENSOR
- CHEMICALLY STRENGTHENED OR THERMALLY FORMED GLASS REFLECTOR
- STRUCTURES BASED ON SHEET METAL, SMC, SANDWICH TECHNOLOGIES

FIGURE 5. SUGGESTED TROUGH DESIGN FEATURES.

Conclusion

In conclusion, our common current aim in line-focus collector technology should be toward engineering development to establish a target collector with high performance, durability, and reliability utilizing mass-production technology with potential for low cost.

References

1. D. E. Randall, "A Compendium of Solar-Thermal Collector Procurement Activities At Sandia Laboratories," SAND 78-2183, Sandia Laboratories, Albuquerque, NM, May, 1979.

2. R. W. Harrigan, "Factors Affecting Market Initiation of Solar Total Energy," 1978 IEEE Region Five Annual Conference, Tulsa, OK, April 16, 1978.

3. L. M. Larsen, Editor, "FY78 Annual Progress Report: Midtemperature Component and Subsystem Development Project," SAND79-0800, Sandia Laboratories, Albuquerque, NM, September, 1979.

4. R. L. Champion, Editor, "FY79 Annual Progress Report: Midtemperature Component and Subsystem Development Project," SAND79-2204, Sandia Laboratories, Albuquerque, NM, to be published.

5. R. E. Allred, D. W. Miller, and B. L. Butler, "Environmental Testing of Solar Reflector Structures," Proceedings of the International Solar Energy Society, Atlanta, GA, June, 1979.

6. G. W. Treadwell, "Design Considerations for Parabolic-Cylindrical Solar Collectors," SAND76-0082, Sandia Laboratories, Albuquerque, NM, July, 1976.

7. A. C. Ratzel, "Evaluation of the Evacuated Solar Annular Receivers Used at the Midtemperature Solar Systems Test Facility (MSSTF)," SAND78-0983, Sandia Laboratories, Albuquerque, NM, July, 1979.

8. A. C. Ratzel, "Receiver Assembly Design Studies for 2-m 90° Parabolic-Cylindrical Solar Collectors," SAND79-1026, Sandia Laboratories, Albuquerque, NM, September, 1979.

9. R. B. Pettit and R. R. Sowell, "Recent Developments Regarding Electrodeposited Black Chrome Solar Coatings," Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receiver, Boulder, CO, January 24-25, 1979.

10. S. M. Kohler and J. L. Wilcoxen, "Development of a Microprocessor-Based Sun-Tracking System for Solar Collectors," SAND79-2163, Sandia Laboratories, Albuquerque, NM, to be published.

11. D. E. Randall, D. D. McBride, and R. E. Tate, "Parabolic Trough Solar Collector Array Wind Loadings," SAND79-2134, Sandia Laboratories, Albuquerque, NM, to be published.

12. H. E. Auld and P. F. Lodde, "Study of Low-Cost Foundation/Anchor Designs for Single-Axis-Tracking Solar Collector Systems," SAND78-7048, Prepared for Sandia Laboratories by University of New Mexico, Albuquerque, NM, January, 1979.

13. H. E. Auld and P. F. Lodde, "Study of Foundation Designs for Single-Axis-Tracking Solar Collector Systems Under Reduced Loading Conditions," SAND79-7016, Prepared for Sandia Laboratories by University of New Mexico, Albuquerque, NM, May, 1979.

14. H. E. Auld, "Analysis of Field Test Results for Single-Axis-Tracking Solar Collector Foundations." SAND79-7023, Prepared for Sandia Laboratories by Higgins, Auld, & Associates, Albuquerque, NM, July, 1979.

POINT-FOCUS COLLECTOR TECHNOLOGY FOR IPH*

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ABSTRACT

The point-focusing distributed receiver concept utilizes a parabolic concentrator which tracks the sun in two axes across the sky. The concentrator collects sunlight from a large area and reflects and focuses it to a very small area. A receiver, which is mounted at the focal point, captures the concentrated radiation and converts the energy to heat in a working fluid such as hot gas or steam. The working fluid transports the energy via flexible lines to a heat-transfer network on the ground to provide process heat. The technology status of the basic concentrator and receiver subsystems is described in the paper.

INTRODUCTION

Parabolic dish, also known as point-focusing, distributed receiver (PFDR) modules are composed of three major subsystems: concentrator, receiver, and power conversion unit.[1,2,3] Components include the various control systems and auxiliary equipment. Two-axis tracking, point-focusing concentrators usually are of paraboloidal shape (Fig. 1).

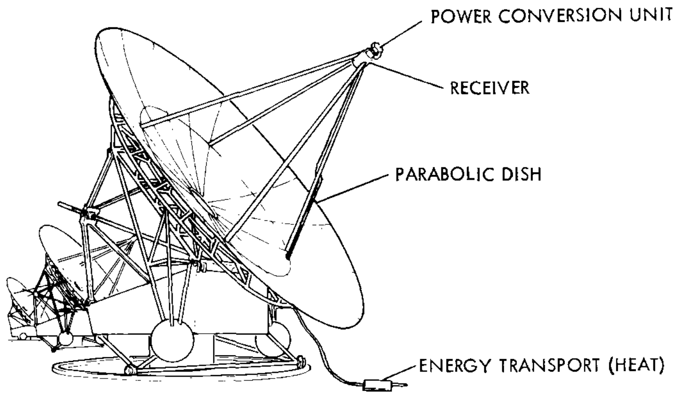

FIGURE 1. TYPICAL PFDR PARABOLIC DISH MODULE

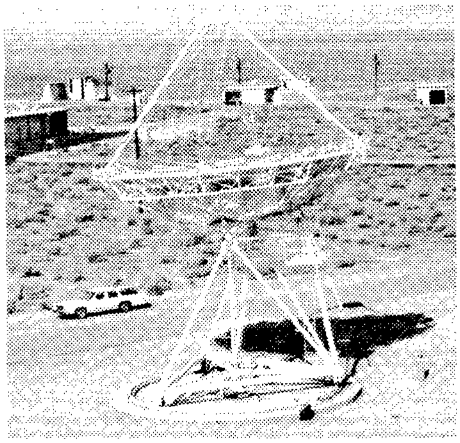

FIGURE 2. TEST BED CONCENTRATOR

The receiver, basically a heat exchanger, is mounted near the focal point and heats a suitable working fluid. The power conversion unit (PCU) for electrical power production consists of a heat engine,

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*The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the U.S. Department of Energy through an agreement with NASA.

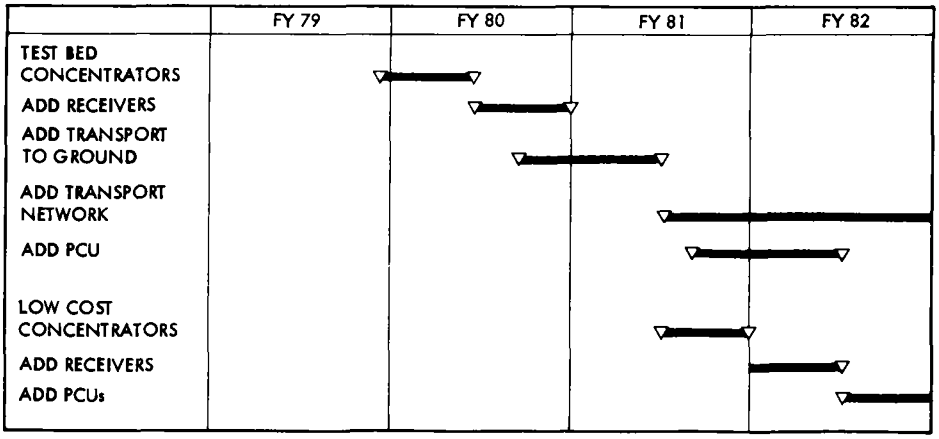
alternator, and associated controls. Each module may supply power to an electric grid. However, several modules (a dish cluster) may be used to a drive a larger engine mounted on the ground. The latter configuration, which requires a thermal transport subsystem, can be utilized to produce process heat. To meet a variety of application needs, second-generation PFDR modules may include energy storage to permit operation during transient cloud cover and overcast days. Both thermal (internal) storage and electric (external) storage may be required.

The PFDR concept offers a high probability for achieving cost-competitive solar power production. The point-focusing feature offers high temperature capabilities. Modularity allows mass production of the basic operating unit with attendant low initial cost and high unit reliability. The modular feature may also present opportunities for reducing operating and maintenance costs because single units can be repaired or replaced in the field without shutting down major portions of the systems. A further advantage of the inherent modularity is the possibility of incremental plant construction and financing, thereby, relieving the need for very large capital investment at the outset of plant construction. The modularity inherent in the distributed receiver concept is expected to satisfy the diverse needs of dispersed applications.

A set of cost and performance targets are being established to meet PFDR Program objectives. First-generation targets are to be completed by 1982, and second-generation targets by 1985. For example, the target cost for first-generation concentrators is $100/m^2$ while for the second generation it is $70/m^2$. Achievement of these and associated targets implies designs which, in mass production, would produce energy at a cost of $5/M Btu in 1985.

The concentrator, receiver and heat transport units are assembled together to form a module. The first concentrator will be the Test Bed Concentrator (TBC). After testing and evaluation of TBC No. 1, a steam receiver will be installed and tested (Table 1).

Table 1. FIRST GENERATION TEST SCHEDULE



Then, a flexible line will be added to transport the steam to the base of the module. The addition of a steam transport network to convey steam from several modules is planned for FY 1981. A similar procedure will be applied with TBC No. 2 which will use air rather than steam. As the first Low Cost Concentrators (LCC) become available, modules based on them will be tested. Testing of second-generation hardware will nominally follow that of the first generation by a few years [4].

CONCENTRATOR DEVELOPMENT

The Concentrator Development Task activities are directed toward developing high-temperature point-focusing concentrator technology, with a major emphasis on low cost in large quantity production. This approach is motivated by the fact that the concentrators comprise more than one-half of the cost of a solar thermal module. The implementation of this task is primarily through contracts with industry.

Leading to early full concentrator test capability, effort is being made on the Test Bed Concentrator. The TBC shown in Figure 2 uses a microwave antenna design modified to accommodate the requirements of solar tracking and to support the receiver/power conversion package at the focal point.

Spherical mirror facets, developed by JPL, were supplied for use as the reflector surface. Two such TBC units were supplied by E-Systems, Inc., Dallas, Texas, and installed at the Point-Focusing Solar Test Site, near Lancaster, California.

Following three parallel competitive preliminary design contracts, the General Electric Company's Space Division is now in the detailed design phase of the first generation Low Cost Concentrator. This design was based on their earlier development of the point focusing concentrators for DOE's Shenandoah Georgia Project. The General Electric design (Fig. 3) utilizes injection molded plastic panels mounted on an internal framework of eight radial ribs. The molding process gives good optical quality since the mold is replicated with high accuracy, while also enabling inclusion of integral structural ribs, attachment points and inserts. The injection molding lends itself to high production rates on automated machinery. Low-cost reflection surfaces can be molded into the panel, eliminating the labor-intensive reflector-application step. The reflector tracks the sun by azimuth and elevation axes driven by a cable and drum system. The elevation axis is a pair of pivots at the rim of the reflectors, permitting the reflector to be stowed in a horizontal position, looking at the nadir. This enhances reflection surface cleanliness, reduces wind loading, and provides access to the receiver/engine.

For the advanced concentrator (Fig. 4) the reflective surface consists of two groups of back-silvered reflective glass mirrors bonded to parabolic structural glass substrates. These mirrored gores are installed in a cantilever fashion on a truss-type backup structural ring. Analysis of this design is being performed by Acurex Corp. Structural glass gore technology is being developed by Pittsburgh-Corning Corp. and Solaramics, Inc.

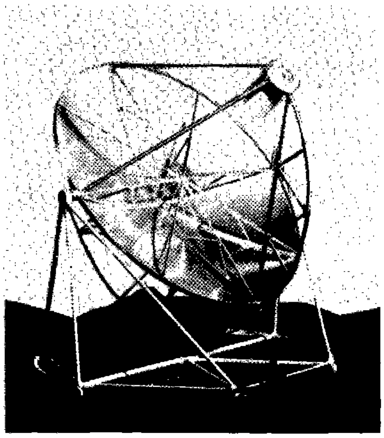


FIGURE 3. FIRST GENERATION LOW COST CONCENTRATOR CONCEPT

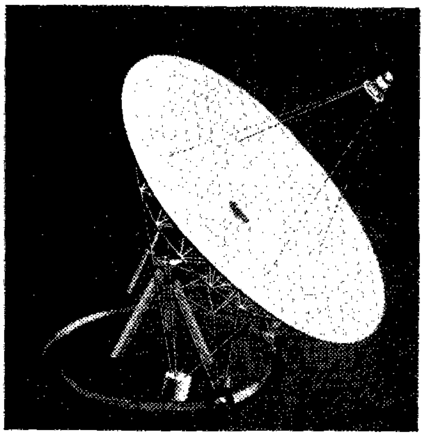


FIGURE 4. ADVANCED CONCENTRATOR CONCEPT

RECEIVER DEVELOPMENT

Figure 5 presents a view of the first-generation steam receiver being developed by Garrett AiResearch Manufacturing Company of California. Sized to accept about 85 kWth of concentrated solar energy, features of this design include: single pass flow to superheated steam and reheat capability for two-stage steam processes. All components of the experimental prototype unit are readily removable; however, large volume production units would largely be of welded construction.

The open-cycle air receiver, shown in Figure 6, is also being developed by Garrett AiResearch. The plate-fin matrix heat exchanger is a high-temperature brazement of rectangularly offset, die-formed Inconel 625 sheets. The inlet aperture reflector skirt is fabricated of silicon carbide.

Final design approval for both the air and steam receivers occurred in October and prototype delivery is scheduled for next spring.

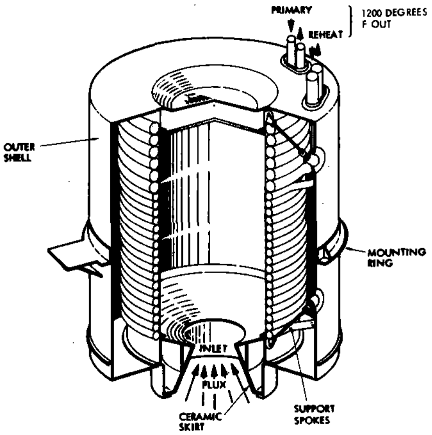


FIGURE 5. STEAM RECEIVER

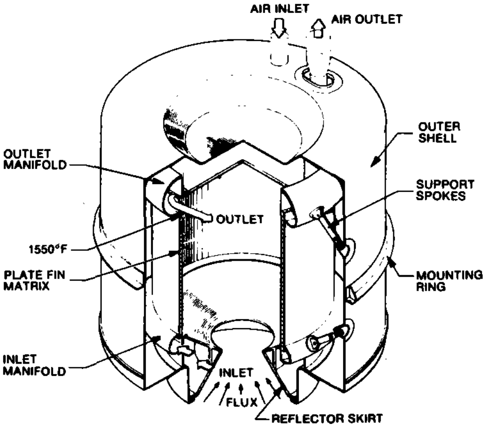


FIGURE 6. AIR RECEIVER

In the advanced receiver area, a 250 kW thermal receiver designed by Sanders Associates (Fig. 7) has been successfully tested to 1075°C (1970°F) with air at the DOE Advanced Components Test Facility at Georgia Tech. Designs utilizing this concept to achieve 1650°C (3000°F) are now being prepared.

Designs based on a ceramic tube concept (Fig. 8) are also being pursued by General Electric Corp. Temperatures in the 1095-1650°C (2000-3000°F) range are planned for designs utilizing a silicon-nitride or silicon-carbide extruded coil surrounding a ceramic buffer sleeve.

SUMMARY

Design and hardware effort is underway on PFDR modules. These modules when mass produced will be capable of producing process heat in a cost-competitive manner.

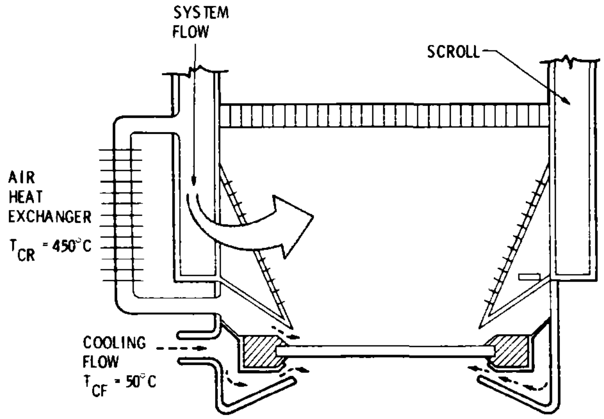


FIGURE 7. CERAMIC MATRIX RECEIVER

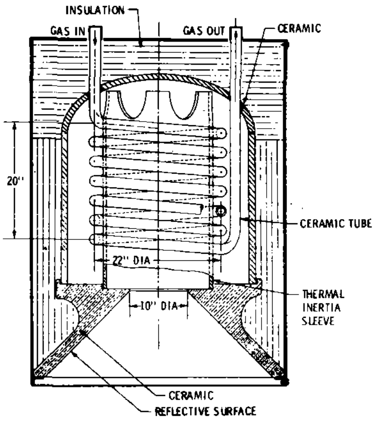


FIGURE 8. COILED CERAMIC TUBE

REFERENCES

1. Truscello, V. C. and A. N. Williams, "Heat and Electricity from the Sun Using Parabolic Dish Collector Systems," Jet Propulsion Laboratory, September, 1979.

2. Lucas, J. W., "Solar Parabolic Dish Thermal Power Systems Technology and Applications," 14th IECEC Meeting, Boston, August, 1979.

3. PFDR Technology Project Annual Technical Report Fiscal Year 1978, Volumes I-II, JPL Publication 79-1, DOE/JPL 1060-7, March, 1979.

4. Advanced Subsystems Development Second Semiannual Progress Report, JPL Publication 79-24, DOE/JPL 1060-6, October, 1978.

QUESTIONS

Question: What applications do you believe your dish collectors will be most appropriate for? Also, what kind of stroage will you use for your collected heat?

Answer: Because the temperature range will be wide (600^{o} - 3000^{o}F) and because of the modularity of dishes the range of possible applications is large; e.g., alcohol generation, enhanced oil recovery, various industrial process heat applications, and generation of fuels and chemicals at the higher temperatures.

Initially the systems can be hybrid which means the energy "storage" will be in fossil fuels. Later, fossil fuels may be replaced by those from biomass. Also, there will be latent heat storage followed by chemical energy storage at room temperature.

Question: You stated that you plan to have your advanced dish design examined by mass production experts. What sort of experts will they be -- people engaged in dish manufacture or people from other industries?

Answer: Mass production costs of the designs will be estimated by production design/cost companies such as those in Detroit, in addition to separate estimates by the respective subsystem designers themselves and by JPL.

Question: What are the cost and performance goals for your dish collector development program?

Answer: For electric power production they are shown in the following Table. For heat production, they are being developed; however, they will be very similar to those for the concentrator and receiver for electric production -- with the addition of heat transport.

Subsystem	Target Item	1982 First Generation (1978 $)	1985 Second Generation (1978 $)
Concentrators	Capital Cost*	\$100 to \$150/m^2	\$70 to \$100/m^2
	Mirror Reflectance	90%	92%
Receivers	Capital Cost*	\$40-60/kWe	\$20-40/kWe
	Efficiency	80%	85%
Power Conversion	Capital Cost*	\$200-350/kWe	\$50-200/kWe
	Efficiency	25 to 35%	35 to 45%

*Range of 1st generation production: 5,000 - 25,000/yr.
Range of 2nd generation production: 10,000 - 1,000,000/yr.

SOLAR CENTRAL RECEIVER SYSTEMS PROGRAM

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ABSTRACT

Major elements of the DOE Solar Central Receiver Systems Program include development of storage-coupled and hybrid system concepts; the Central Receiver Test Facility in Albuquerque, NM; the pilot plant under construction at Barstow, CA; proposed repowering/industrial retrofit plants; and heliostat, receiver, and storage subsystems development work. Current and proposed activities within each element are discussed.

INTRODUCTION

The Department of Energy (DOE) Solar Central Receiver Systems Program has three main elements: (1) development of systems concepts, (2) projects to demonstrate and further the development of the concepts, and (3) component development to support the systems. The goal of the program is to develop technologies for improving the cost effectiveness and for increasing the potential breadth of application of the central receiver concept. A summary of the major elements and subelements of the program is presented in Table I.

SYSTEMS CONCEPTS

The storage-coupled central receiver concept (Figure 1) consists of a field of individually guided mirrors (heliostats) that redirect the sun's energy to a receiver mounted on a tower. In the receiver, the radiant solar energy is absorbed in a circulating (working) fluid, and then is either used to power a turbine or transferred to a storage system for use during a later period. For an industrial process heat (IPH) application, the process would replace the turbine in Figure 1.

Development has been conducted on designs which use one of five different working fluids: air, helium, salt, sodium, or water/steam. For power generation, the air and helium systems are coupled to a Brayton

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†This work was supported by the U.S. Department of Energy under Contract DE-AC04-76DP00789.

cycle turbine; the salt, sodium, and water/steam systems are coupled to a Rankine cycle turbine. A water/steam receiver design was selected for the Barstow Pilot Plant. Sandia has awarded contracts to Babcock and Wilcox, Combustion Engineering, and Martin Marietta for the design of improved water/steam receivers. Conceptual designs for advanced storage-coupled systems based on air, sodium, and salt receivers have already been completed. Martin Marietta (salt) and General Electric (sodium) designs have been selected to receive additional funding. Each will design, fabricate, and test at the CRTF a 3- to 5-MW_t experimental receiver.

TABLE I

MAJOR PROGRAM ELEMENTS

Development of Systems Elements
- Storage-Coupled
- Hybrid
- Repowering/Industrial Retrofit

Projects
- CRTF - Central Receiver Test Facility
- Barstow Pilot Plant
- IEA - International Energy Agency Small Solar Power System Project
- Repowering/Industrial Retrofit
- DOE/EPRI Hybrid
- Fort Hood
- Cogeneration

Component Development
- Receivers
- Heliostats
- Storage

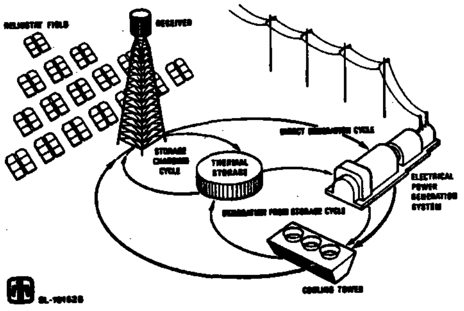

Figure 1. Storage coupled

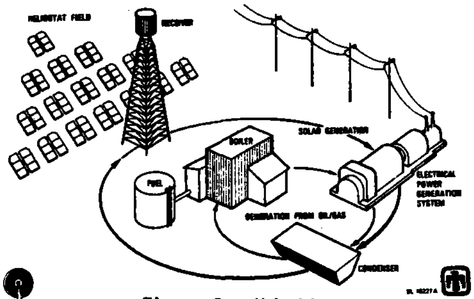

Figure 2. Hybrid

A solar central receiver hybrid system (Figure 2) consists of a solar energy collection subsystem and a non-solar energy subsystem at a single, common site. Typically, the overall system would be operated in an intermediate or base capacity mode so that the output is essentially independent of variations in insolation. The non-solar sources may be fossil-fueled, hydro-electric, geothermal, etc.

Two hybrid configurations are possible -- parallel and series. In the "parallel" configuration, the solar central receiver is capable of fully satisfying the system load under conditions of adequate insolation; at other times, the solar input is supplemented, or completely replaced, by thermal energy from the non-solar source. The system also incorporates a thermal storage unit, which is charged with excess energy from the receiver, and discharged to the inlet port on the turbine prime mover. In the "series" arrangement, the non-solar source may provide supplemental energy as before, maintaining full turbine inlet temperature or pressure under reduced insolation conditions; it may also be employed on a continuous basis to enhance the overall performance of the plant (as, for example, by the use of fossil fuel combustion to increase the temperature or pressure of the working fluid above a limit imposed by solar receiver material constraints). Many other combinations and interface arrangements are possible; for example, the solar and non-solar inputs may be combined at a later stage in the energy conversion sequence by mechanical or hydraulic coupling of separate prime movers or even at the primary terminals of the plant output transformer in the case of power production.

Bechtel, Energy Systems Group, and Martin Marietta are currently developing hybrid designs with DOE funding. These studies were initiated early in 1979 with the first phase completion dates set for late 1979. In addition, the Bureau of Reclamation, with partial DOE funding, is studying the incorporation of central receiver plants into their hydroelectric network.

Repowering of existing electrical generation plants and retrofitting of existing industrial processes with solar capability are two additional systems concepts under DOE-funded development. In September twelve contracts, six in each category, were awarded for site-specific conceptual design. A summary of the twelve contracts is shown in Tables II and III. Following the conceptual designs, it is planned to reopen competition for project design and construction of one or two plants in each category.

PROJECTS

The Central Receiver Test Facility (CRTF) in Albuquerque has been fully operational since the summer of 1978. The facility has 222 thirty-seven square meter heliostats which can produce beams of concentrated solar radiation at a number of target areas located along a 61-meter tower. An extensive program is being conducted at the CRTF to obtain experimental data on receiver performance. Testing of a 1-MW_t prototype receiver developed by Boeing under EPRI funding is complete. The 5-MW_t McDonnell Douglas test panel has been installed and testing will be completed in December 1979. Other receiver tests that have been scheduled include the EPRI/Black & Veatch ceramic receiver, and the advanced receivers being developed by Martin Marietta and General Electric.

The second major central receiver project is a 10-MW_e pilot plant under construction at Barstow, California. The plant will have a water/steam receiver and use 1700 heliostats, each with an area of 40-45 m^2. Initial operation is scheduled for late 1981. The plant will be operated by the Southern California Edison Company as a part of their network.

TABLE II

REPOWERING CONTRACTS

CONTRACTOR	LOCATION	APPLICATION	TECHNOLOGY
Arizona Public Service	Phoenix, AZ	Electrical Generation	Molten Salt Central Receiver
El Paso Electric	El Paso, TX	Electrical Generation	Water/Steam Central Receiver (with Solar Reheat Receiver)
Black & Veatch	Tulsa, OK	Electrical Generation	Water/Steam Central Receiver
Rockwell	Monahans, TX	Electrical Generation	Sodium Central Receiver
McDonnell Douglas	Yerington, NV	Electrical Generation	Molten Salt Central Receiver
General Electric	Earth, TX	Electrical Generation	Sodium Central Receiver

TABLE III

INDUSTRIAL RETROFIT CONTRACTS

CONTRACTOR	APPLICATION	RECEIVER	TEMPERATURE (C°)	PEAK SOLAR INPUT (10^6BTU/hr)
Boeing	Gypsum Board Drying	Air	575	37
Martin Marietta	Enhanced Oil Recovery	Water/Steam	290	100
McDonnell Douglas	Uranium Ore Processing	Water/Steam	200	40.3
Foster Wheeler	Oil Distillation	Water/Steam	260	147.4
Northrup	Process Natural Gas	Oil	300	51
PFR	Reforming - NH_3	Gas Cavity	800	125

A third project (with partial U.S. funding) is the IEA Small Solar Power System. Two 0.5 MW_e solar thermal plants are to be constructed at Almeria, Spain. One of the plants will be a central receiver system and one a distributed collector system. Detailed designs have been started with initial operation also slated for mid-1981.

COMPONENT DEVELOPMENT

In addition to the receiver development work already mentioned, a radiant test of a five-tube water/steam receiver panel is being tested by Sandia Laboratories. The panel has been heavily instrumented in order to obtain a better understanding of once-through boiling phenomena. Completion of the testing is scheduled for December, 1979.

An extensive heliostat development program is underway. The objective of the program is to meet initial cost, performance, and operating and maintenance cost goals that have been established. The attainment of these goals, in conjunction with cost targets for other subsystems, is expected to provide a competitive alternative to the use of oil and natural gas for electric power generating utilities and IPH users by the late 1980's.

Sandia Laboratories has awarded contracts to McDonnell Douglas, Martin Marietta, Westinghouse, Northrup, and Boeing for design, fabrication, and testing of second-generation heliostats. In addition, efforts have already been started with respect to components and equipment that will contribute to third-generation designs. A variety of special studies either recently completed or currently under way include:

- Inverted Stowage Study - McDonnell Douglas
- Field Reflectometer Development - Beckman
- One-Piece Plastic Dome Development - Boeing
- Plastic Film Development and Aging Studies - General Electric
- Mirror Deterioration Studies - Sandia Laboratories
- Heliostat Component Development - McDonnell Douglas
- Drive System Development - Solaramics
- Westinghouse Heliostat Testing - Sandia Laboratories
- Mirror Silvering Specifications - Battelle
- Solarization/Weathering of Glass - Sandia Laboratories

Primary responsibility for the development of new energy storage methods rests with the DOE Division of Energy Storage. With respect to solar applications, the objective of the storage program is to develop technologies that provide: (1) first generation storage subsystems for those solar thermal applications that presently have no storage subsystem under development; and (2) advanced alternatives offering cost/performance improvements over the first generation storage subsystems currently being developed. The three elements of the program are buffering storage, diurnal storage, and advanced technologies. Baseline storage technologies include: rock and oil; single and multiple tank oil, dual media; single and multiple tank sodium or salt, and Alumina brick checkerwork.

Some storage development also has been done as a part of the Solar Central Receiver Systems Program. Martin Marietta is developing internal insulation for tanks to store molten salt. In addition, an oil sidestream processor is being developed by Martin Marietta for possible use in the Barstow pilot plant.

ACKNOWLEDGMENTS

In the preparation of this paper, the author drew heavily on two references:

L. N. Tallerico and A. C. Skinrood, "Solar Central Receiver Program", Presented at Fourtheenth Intersociety Energy Conversion Engineering Conference, Boston, Massachusetts, August 9, 1979.

L. N. Tallerico (Ed.), "A Description and Assessment of Large Solar Power Systems Technology", Sandia Laboratories Report SAND79-8015, August 1979.

QUESTIONS

Question: How do you see the cost effectiveness of central receivers at lower temperatures compared to lower temperature collectors?

Answer: Our estimate indicates that central receivers are competitive for temperatures greater than 200°F, in particular for systems larger than about 2 mega watts.

Technology Assessment - II

SOLAR REFLECTANCE, TRANSMITTANCE AND ABSORPTANCE OF COMMON MATERIALS

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ABSTRACT

The solar reflectance, transmittance and absorptance of common materials used for solar collector fabrication have been compiled for easy reference. The data are derived from solar weighted averaging techniques and can be used for initial calculations of collector performance.

INTRODUCTION

To calculate the efficiency of a solar collection system, one must know the appropriate solar and infrared spectral properties for the optical components. For flat plate systems one must have the optical properties of the glazing and absorber materials in both the solar (0.3 μm to 2 μm) and thermal infrared (2 μm to 30 μm) spectra to account for solar reflectance losses and the redistribution of thermal energy respectively. For concentrating systems using a transmitting element such as a fresnel lens or for air inflated point and line focus collector systems fabricated from thin polymer films the solar transmittance of the material becomes most important. For reflecting concentrators, it is necessary to know the solar reflectance of the mirror of interest. This paper compiles an up-to-date listing of the optical properties of a wide variety of common materials used to fabricate solar collectors. The data results from measurements on average pieces of material delivered through the normal commercial supply system and thus should represent the material performance which a solar collector manufacturer might expect. Caution should be used if the materials of interest for a particular collector system have been specially fabricated or compounded to provide "better" optical properties.

The data presented in this paper should be sufficiently accurate to provide a reasonable calculation of the expected performance of a specific solar system. In addition to providing performance data, the data is organized into tables which give performance values and some indication of the stability of the materials as a function of time of solar radiation exposure. These are qualitative estimates based on our accumulative exposure experience and are not derived in a scientific manner. The numbers are guidelines to materials selection and should not be used to attempt to predict system lifetimes.

RESULTS AND DISCUSSION

The properties of a number of polymeric materials including transmittance data are shown in Table 1 [1-5] and were compiled to allow the performance of flat plate solar collectors to be calculated. The solar and infrared transmittance can be used to develop a thermal balance equation for a collector operating at a given solar flux input and fluid inlet and outlet operating temperatures. In addition, knowledge of the refractive index also allows the calculation of how these materials would perform as concentrating elements such as fresnel or common lenses. Sample calculations and detailed use of this data is illustrated in reference [1]. The cost of transmitting materials varies widely and must also be considered in the materials selection process.

One should remember that in calculating the daily performance of a collector the reflectance loss changes as a function of the angle and the refractive index. It should also be noted that these properties are taken for materials with a smooth surface and that an abraded or otherwise disturbed surface can drastically alter the interface reflection loss and thereby effect the transmittance of the material. For transmitting concentrator applications, the surface smoothness and contour are extremely important and must be taken into account when trying to calculate the concentration ratio and collector performance.

Reflecting materials used to augment flat plate collectors or as reflecting elements in concentrating collectors must have both high absolute reflectance in the solar spectrum and high specularity. Specularity is the ability to reflect a ray without significantly broadening that ray. The poorer the specularity of the mirror, the larger the receiver must be in order to capture the sun's reflected energy due to the broadening of the solar image caused by the mirror itself. The sun's image can be further degraded by the attachment technique used to afix a thin film mirror to a supporting substrate, i.e., a very non-uniform adhesive layer can introduce waviness and roughness to the reflector surface. Table 2 provides reflectance data for mirror materials in low, intermediate and high concentration applications. Based on the spatial scattering profile measured for real mirror surfaces an expression for the reflectance [$R(\Delta\theta)$] is derived in reference[6]as a function of the angle ($\Delta\theta$) from the specular direction. In general the specular profile is found to be comprised of the sum of two normal distributions. The angle subtended by the receiver (τ) in a solar concentrator determines the effective reflectance for that particular system and is given by

$$(1)\quad \tau = 2\tan^{-1}(D/2x)$$

where D is the receiver diameter and x the distance from the reflector to the receiver. The effective reflectance R' is given by

$$(2)\quad R'(\tau) = \int_{-\tau/2}^{+\tau/2} R(\Delta\theta)\, d(\Delta\theta)$$

and Table 2 compiles estimated R' values for apertures of 4, 10, and 18 milliradians. Most single axis concentrating systems have subtended angles greater than 18 milliradians. It is only when the mirror to receiver distance gets quite large as in heliostat or extremely large line focus arrays that numbers less than 4 milliradians are found. Table 2 will allow the system designer to approximate the new reflectance of a mirror. Washing should bring the mirror back to close to its original reflectivity but may not bring it back to the full value if surface abrasion has been caused by the cleaning procedure. This degradation is especially a problem for plastics and metals. Again, the lifetimes of the materials have been qualitatively evaluated and cost should be determined prior to a materials selection.

The ability of a material to absorb sunlight is quite important, and the solar absorptance of a number of commonly available materials is given in Table 3. Some of these materials have--in addition to a high solar absorptance--low thermal emittance and therefore are called selective absorbers. The benefit of a selective absorber is that it will suppress reradiation of thermal energy from the receiver surface. A detailed description of absorber materials applications and the nature of selective absorber materials can be found in reference [7]. The major tradeoff between selective and non-selective materials is cost versus performance. Non-selective materials tend to cost much less than the selective materials; however, selective absorbers are frequently chosen for flat plate and concentrator applications because of the improved performance which can be obtained. In flat plate solar systems a rule of thumb is that a collector with a single glazed selective absorbing surface is roughly equivalent to a collector with a double glazed non-selective absorbing surface collector. The increased cost of the absorber surface may be offset by the elimination of one glazing layer. Selective materials are commonly applied by electrodeposition; non-selective materials are applied by painting; both can be applied to large areas. The thermal stability of the available materials is qualitatively given, but it is important to check the absorber material of interest in the particular application before making any claims as to actual system life.

SUMMARY AND CONCLUSIONS

The data presented in this paper are indicative of the range of optical properties of materials which are available to solar collector designers at this time. A significant amount of research is taking place to quantify the stability of the available materials and to identify new or improved materials which could be added to these lists. The tables give nominal numbers for the commercially produced materials. The service life at these performance levels will depend on proper cleaning and maintenance. In addition, batch-to-batch variations in materials could also give small variations in these optical properties. If there is uncertainty regarding a value, the appropriate property of the actual material used in the collector should be measured to provide the most accurate system performance calculation. These numbers are offered as a preliminary guide to the selection and use of materials in solar collector designs.

REFERENCES

1. Jorgensen, G. J., "Long-Term Glazing Performance," Proceedings of Solar Glazing: 1979 Topical Conference, Mid-Atlantic Solar Energy Association, June, 1979, (SERI/TP-31-193).
2. Ratzel, A. C., and Bannerot, R. B., "Commercially Available Materials for Use in Flat-Plate Solar Collectors," Proceedings of 1977 Flat-Plate Solar Collector Conference, CONF-770253, 387 (1978).
3. Eidin, F. E., and Whillauer, D. E., "Plastic Films for Solar Energy Applications," Proceedings of the United Nations Conference on New Sources of Energy, Vol. 4, Rome, August 21-31, 519 (1961).
4. Kynar 500. Polyvinylidene Fluoride for Architectural Finishes. Pennwalt Corporation, Plastics Department, Three Parkway, Philadelphia, Pennsylvania. Brochure PL138-677-5M-B.
5. Hummel, D. O., Infrared Analysis of Polymers, Resins and Additives, an Atlas, Vol. 2, Part 2, Wiley-Interscience, New York (1969).
6. Butler, B. L., and Pettit, R. B., "Optical Evaluation Techniques for Reflecting Solar Concentrators," SPIE 114, 43 (1977).
7. Call, P. J., "National Program Plan for Absorber Surfaces R&D," Chapter 9, Properties of Polycrystalline and Amorphous Thin Films and Devices, L. L. Kazmerski, Editor; Academic Press (1979) (SERI/TR-31-103).

TABLE I

THERMAL AND OPTICAL PROPERTIES OF COVER PLATE MATERIALS [1]

Material	Index of Refraction	Normal Incident Short-wave Transmittance (λ=0.4-2.5μ)	Normal Incident Long-wave Transmittance (λ=2.5-40μ)	Thickness* (m)	Density (kg/m^3)	Specific Heat (J/^{0}K-kg)	Thermal** Capicity (W-hr/^{0}K-m^2)	References
Glass	1.518	0.840	0.020	$3.175\text{x}10^{-3}$	$2.489\text{x}10^{3}$	$0.754\text{x}10^{3}$	1.659	(2)
Fiberglass Reinforced Polyester (Sunlite)	1.540	0.870	0.076	$6.350\text{x}10^{-4}$	$1.399\text{x}10^{3}$	$1.465\text{x}10^{3}$	0.361	(2)
Acrylic (Plexiglas)	1.490	0.900	0.020	$3.175\text{x}10^{-3}$	$1.189\text{x}10^{3}$	$1.465\text{x}10^{3}$	1.534	(2)
Polycarbonate (Lexan)	1.586	0.840	0.020	$3.175\text{x}10^{-3}$	$1.199\text{x}10^{3}$	$1.193\text{x}10^{3}$	1.260	(2)
Polytetrafluoroethylene (Teflon)	1.343	0.960	0.256	$5.080\text{x}10^{-5}$	$2.148\text{x}10^{3}$	$1.172\text{x}10^{3}$	0.036	(2,3)
Polyvinyl Fluoride (Tedlar)	1.460	0.920	0.207	$1.016\text{x}10^{-4}$	$1.379\text{x}10^{3}$	$1.256\text{x}10^{3}$	0.049	(2)
Polyester (Mylar)	1.640	0.870	0.178	$1.270\text{x}10^{-4}$	$1.394\text{x}10^{3}$	$1.046\text{x}10^{3}$	0.051	(2)
Polyvinylidene Fluoride (Kynar)	1.413	0.930	0.230	$1.016\text{x}10^{-4}$	$1.770\text{x}10^{3}$	$1.256\text{x}10^{3}$	0.063	(4), Fig.2
Polyethylene (Marlex)	1.500	0.920	0.810	$1.016\text{x}10^{-4}$	$0.910\text{x}10^{3}$	$2.302\text{x}10^{3}$	0.059	(3,5),Fig.2

* These values correspond to the thickness associated with the stated transmittances. They were used in the simulations to compute thermal capacity and are representative of commercially available film thicknesses.

**Thermal capacity = (Thickness) (Density) (Specific heat)

TABLE 2

SPECULAR REFLECTANCE PROPERTIES OF SEVERAL MIRROR MATERIALS[6]

Material	Supplier	Estimates of Solar Weighted Reflectance[b] R'(τ)			
		τ=4mr	10mr	18mr	$R_s(2\pi)$
I. Second-Surface Glass					
(a) Laminated Float Glass - 2.7 mm thick - silvered	Carolina Mirror Co.	0.83	0.83	0.83	0.83
(b) Laminated Low-Iron Sheet Glass - 3.35 mm thick - silvered	Gardner Mirror Co.	0.90	0.90	0.90	0.90
(c) Corning Silvered Microsheet Co.-0.114 mm thick - Mounted on optically flat plate	Corning Glass	0.76	0.87	0.92	0.95
(d) Corning 0317 Glass - 1.5 mm thick - Evaporated silver	Corning Glass	0.95	0.95	0.95	0.95
II. Metallized Plastic Films					
(a) 3M Scotchcal 5400 Laminated to backing sheet	3M Company	0.60	0.84	0.85	0.85
(b) 3M FEK-163 Laminated to backing sheet	3M Company	0.83	0.85	0.85	0.85
(c) Aluminized 2 mil FEP Teflon (G405600) Laminated to backing sheet	Sheldahl	0.70	0.81	0.82	0.87
(d) Silvered 2 mil FEP Teflon (G400300) Mounted on Optically Flat Plate	Sheldahl[a]	0.73	0.82	0.90	0.96
(e) Silvered 5 mil FEP Teflon (G401500) Mounted on Optically Flat Plate	Sheldahl[a]	0.77	0.83	0.89	0.95
(f) Front Surface Aluminized Mylar (200XM648A) stretched membrane	Boeing	0.88	0.88	0.88	0.88
III. Polished, Bulk Aluminum					
(a) Alzak Type I Specular	Alcoa				0.85
Perpendicular to rolling marks		0.61	0.68	0.76	
Parallel to rolling marks		0.68	0.76	0.83	
(b) Kinglux No. C4	Kingston Ind.				0.85
Perpendicular to rolling marks		0.67	0.71	0.75	
Parallel to rolling marks		0.69	0.71	0.75	
(c) Type 3002 High Purity Al - Buffed and Bright Anodized	Metal Fabrications, Inc.[a]	0.44	0.60	0.71	0.84

a) Experimental materials not produced in high production, so cost information is lacking.

b) Estimated from ≈500 nm specularity data ref. [6] and solar weighted total hemispherical reflectance data. Standard deviation of the estimates is about 2%.

TABLE 3

PROPERTIES OF SELECTED COMMERCIAL SOLAR ABSORBER SURFACES [7]

Material	Technique	Supplier(S)/ Developer(D)	α_s	ε_t(T)	T Stability** (°C)
Black Chrome	electro-deposited	Many	0.94-0.96	0.05-0.10(100) 0.20-0.25(300)	300
Pyromark	paint	Tempil	0.95	0.85(500)	<750
S-31 (nonselective)	paint	Rockwell International	0.8-0.85	0.8-0.85	>550
SOLARTEX	electro-deposited	Dornier (W. Germany)	0.93-0.96	0.14-0.18(310)	700
SOLAROX (proprietary)	"	"	0.92	0.20	200
Black Epoxy	paint	Amicon Corp.	NA	NA	NA
436-3-8	"	Bostik (U.S.M. Corp.)	0.90	0.92	NA
Enersorb	"	Desoto	0.96	0.92	NA
7729	"	C. H. Hare	0.96	0.90-0.92	NA
R-412	"	Rusto-leum Co.	0.95	0.87	NA
5779	"	"	0.95	0.90	NA
Nextel (nonselective)	"	3-M	0.97-0.98	>0.90	150
NOVAMET 150 (proprietary)	"	Ergenics	0.96	0.84	800 (1 hr)
MAXORB	(proprietary)	Ergenics	0.97(±.01)	0.10(±.03)	150(20 wks) <400(1 hr)
Tabor Black (NiS/ZnS)	electrodeposited + overcoat	Miromit	0.91	0.14	-

QUESTIONS

Question: What effect, if any, will increased flow rates have on materials--pipes, seals, pumps, heat exchangers, etc.? (Increased flow with smaller pipes diameters has been suggested to decrease steady state and transient thermal losses.)

Answer: The effect could be increased erosion/corrosion at bends, joints and flow constrictions in flowing systems.

CANDIDATE THERMAL ENERGY STORAGE TECHNOLOGIES FOR SOLAR INDUSTRIAL PROCESS HEAT APPLICATIONS

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ABSTRACT

The successful application of solar industrial process heat (SIPH) will depend, in part, on the use of thermal energy storage (TES) to provide continuous operation during periods of solar isolation. A number of candidate TES system elements have been identified as having the potential of meeting this need. These elements which include storage media, containment and heat exchange are shown. Recently completed system studies on selected industries have identified a number of processes where TES appears attractive. These systems and the suggested TES subsystems are shown and discussed.

INTRODUCTION

A necessary requirement for the successful application of solar thermal energy to industrial processes is the need to provide continuous operation of the processes during periods of solar isolation. The degree of acceptance and utilization of solar energy will therefore depend upon the successful development and integration of thermal energy storage (TES) subsystems with the solar industrial process heat (SIPH) installation. The technology base for candidate TES subsystems is being investigated and expanded by DOE-funded programs to include a wide selection of media, containment, and heat exchange in a temperature range of 250-1100°C (500-2000°F). Current TES emphasis for solar application is on buffered storage (.5 to 2 hours), however, some of the same technologies could be applied to larger storage capacities (diurnal applications). Studies and development of advanced storage subsystems are being undertaken to identify solar industrial process heat systems in the intermediate to high temperature range. These activities will provide the basis for a detailed technical and economic evaluation of the most promising storage subsystems. Selected storage approaches will be coupled with specific applications and analyzed in detail.

The Department of Energy Division of Energy Storage Systems (DOE/STOR) has the responsibility for formulating and managing research and development in energy storage technologies. Major responsibility for project management in selected areas has been assigned to DOE national laboratories and other government agencies. The current management structure and major area of development for the lead laboratories is shown in Figure 1. The lead center will provide overall management for the TES program including planning, integration and coordination of the involved lead laboratories. Lead laboratories will be delegated prime responsibility and appropriate authority for the day-to-day management and implementation of activities in their designated areas.

THERMAL ENERGY STORAGE TECHNOLOGIES

Figure 2 illustrates the interdependency of the various system elements. The end use application will define the TES subsystem design and operational requirements. The designer's function will be to select the TES subsystem elements which best meets these requirements while considering the many constraints including technical, economic, environmental, institutional and other factors. It is evident that with the variety of storage media available and various types of containment and heat exchange, a large number of combinations are possible. To minimize the development complexity and costs, it has been necessary to limit the number of TES concepts. For near-term applications, the major development effort has been directed to the utilization of existing technologies. This has included sensible heat media, low pressure containment and above ground installations. For advanced systems, both sensible and latent heat media are being studied and tested. Figures 3a, b and c illustrate the variety of media currently being considered, the planned operational temperature range for the media and the investigators or proponents for the concept. An attempt is being made to cover the anticipated end use operational temperature range with the selection of at least one medium for a given temperature. This is shown in Figures 3a, b and c, where various types of media have been selected to cover any given temperature range.

TES Containment, Figure 4, shows the divergent technologies which have been proposed for TES media containment. Most of these advanced concepts have addressed the containment problem associated with high temperature, high pressure water. Descriptions for the various concepts can be obtained from the designated references. Similarly, for latent heat applications of molten salts a variety of heat exchange concepts have been proposed, Figure 5. The withdrawal of heat energy from the molten salt at the solidification temperatures results in the deposition of a solid salt layer on the heat transfer surface. Since salts generally have low heat transfer coefficients, this results in a high and variable resistance to heat transfer. The active heat exchange concepts are being developed to minimize this problem. Figure 6 illustrates a concept currently under investigation at Honeywell Inc. The system employs a molten $NaNO_3$-NaOH mixture as the energy source. The molten salt is pumped into the reflux boiler and water from the condensate stream is directly injected into the salt. The saturated water vapor which is generated is conducted to the condenser as a result of the existing pressure differential within the system and the energy is transferred to the cycle working fluid. The molten salt in passing through the boiler loses only a small amount of its energy. Under these conditions, the selected salt mixture (a dilute eutectic) forms a two-phase slush which is returned to the storage tank where phase separation occurs and the molten salt is recycled.

INDUSTRIAL PROCESS AND REJECT HEAT APPLICATIONS

The "Energy Policy and Conservation Act" (EPCA) Public Law 97-163 was passed by the 94th Congress on December 22, 1975. Part D of Title III of this Act required that FEA establish a program to promote increased energy efficiency in the United States industry. This program included the identification and ranking of major energy-consuming manufacturing industries, the establishment of energy efficiency improvement targets for the ten most energy consumptive industries, and the identification of major energy-consuming corporations within the targeted industries for the purpose of reporting industry progress in improving energy efficiency.

DOE assigned with the responsibility of conservation released a Program Research and Development Announcement (PRDA) in January 1977 to identify industrial processes where process or reject heat recovery systems using TES could be beneficial. Recently completed system studies on selected industries have identified a number of processes where TES appears attractive. These included the food processing, paper and pulp, iron and steel, and cement industries. Subsequent to these studies, it was discovered that the Scandinavian paper and pulp industry and a few companies within the United States are already using TES in their processes. As a result, a contract has been placed for the collection and dissemination of the available TES information to the American paper and pulp industry.

Food Processing

The food processing industry is a major user of low temperature (below 120°C) process heat. The industry requires energy at the rate of 1×10^{15} BTU/YR (1 Quad), and this places the industry sixth among the nations largest energy consumers. Within the food industry the canning segments (SIC 2032 and 2033, canned specialties and canned fruits and vegetables) require 70×10^{12} BTU input annually which represents about 7% of the food industry total. Low pressure steam 0.7 MPa (100 psig) produced on site is generally the source of energy, and it is directly used by infusion and by processes that require a steam atmosphere. Other processes require hot water which is produced by steam/water heat exchange or by cold water-steam infusion. These processes or process-related operations include: cooking, sterilizing, pasteurizing, can- washing and clean-up. This study was performed by the Westinghouse Electric Corporation in cooperation with the Heinz USA - Pittsburgh Division of the H. J. Heinz Company and was funded by the U.S. Department of Energy (Contract EC-77-C-01-5002) and managed by the Oak Ridge National Laboratory. A schematic of a proposed TES/Waste Heat Recovery System in a Food Processing Plant is shown in Figure 7 for the Heinz USA - Pittsburgh plant. Waste heat from these operations are in the 40-95°C (100-200°F) temperature range and can be separated into high temperature (above 60°C) and low temperature (below 60°C) streams. The energy in the high temperature stream only will be used recuperatively through conventional heat exchange to fresh water. This isolation will prevent contamination of the water used in the food processes. The recuperated fresh water is sent to the TES module for later usage or heated to process temperatures by steam heat exchange or hot water infusion and returned to the process. Water that is accumulated in storage during the production period will be used for clean-up operations during the night shift. The estimated energy savings for this installation is in excess of 32 TJ/YR ($3x10^{10}$ BTU/YR), and based on a duplicate system cost of $190,000 the return-on-investment is computed to be better than 30%. A sole-source procurement is currently being negotiated with Heinz USA to install a demonstration system in their Pittsburgh facility.

Iron and Steel

The primary iron and steel industry consumes about 11% of the total national industrial energy usage. The Rocket Research Company with support from the Bethlehem Steel Company and the City of Seattle Lighting Department conducted a study entitled "Application of Thermal Energy Storage Techniques to Process Heat and Waste Recovery in the Iron and Steel Industry". Waste heat recovery in the temperature range of 315-1540°C (600-2800°F) was indicated as being potentially recoverable. The system selected in the study is shown in Figure 8. Waste energy from the primary arc furnace evacuation system is passed through an operational store TES module which acts as a buffer to dampen the temperature variations which are inherent in the furnace discharge. The fume stream is then passed through the peaking store TES module where the energy is stored as sensible heat in a packed bed (refractory brick, slag or scrap steel) and is exhausted through the baghouse. During discharge from storage, the gas flow in the peaking store TES loop is reversed and the heated gases are blended with the discharge gases from the operational store TES discharge in the mixing valve, passes through the heat exchanger and into another mixing valve. Part of the flow is recirculated through the peaking store TES module and the remainder passes to the baghouse. A steam-driven turbine operates to generate power for peak shaving (either in-plant or for utility area demand peaks).

The proposed conceptual system for the Bethlehem plant could result in an estimated payback period of five years depending on the combination of electricity costs and the size of the power generation equipment. Assuming fossil fuel is used to produce peak power, the potential oil savings for a 7 MW_e generator operating 300 days/year would be 16,000 bbl. Overall industry oil savings could approach $2x10^6$ bbl.

Cement

The cement industry is the sixth largest user of industrial energy in the United States. The majority of this energy (80%) is consumed as fuel in the operation of the kilns, however, less than 50% of the energy input is required in the chemical reaction to form clinkers. Martin Marietta Aerospace with team members Martin Marietta Cement and the Portland Cement Association, investigated the use of TES in conjunction with current reject heat usage in the cement industry. Details of this study are contained in the final report "Application of Thermal Energy Storage in the Cement Industry". Waste heat from the kiln is obtained from the gas effluent and from the clinker cooler excess air. This is illustrated in Figure 9 where two TES modules using solid sensible heat storage material, such as, magnesia brick, granite, limestone or cement clinkers are shown. The exhaust gas heats the high temperature bed to 815°C (1500°F) while the clinker cooling gases heats the low temperature bed to about 235°C (450°F). The modules are discharged in a series flow to supply ambient air heated to 650°C (1200°F) to the waste heat boiler where steam is generated to produce electricity. A 10 MW_e output is planned to operate continuously. This requires that 80-90% of the exhaust flow go directly to the boiler with the balance going into storage. At this rate, storage would be fully charged (240 MW_ehr capacity) in one week.

The economic analyses of the system indicates that for the proposed installation the cost would be 10 million dollars and a ROI of 90% is anticipated for a 30 year system life and an average energy cost of 2.8¢/kwh. About 15% of this ROI is attributed to the TES system. The potential energy savings for the cement industry is $4x10^6$ bbl of oil.

SOLAR POWER GENERATION

A concept which utilizes a moving bed of free-flowing solid granules or microspheres as a mechanism for heat absorption, storage, and transfer to a working fluid has been proposed by the Babcock and Wilcox Company for Solar application. This concept is shown in Figure 10. Silica sand or fused silica microspheres are transferred upward by Archimedes pumps from the steam generator discharge to the solar collector where the free-flowing sand is heated to 540°C (1000°F) as it flows downward through vertical tubes in the collector. A portion of this heated sand is directed to the steam generator via the central supply tube and the remainder is put into storage. The heated sand refills the storage bin as cool sand is displaced from the bottom until the heating cycle is completed. During the night, high temperature sand from storage supplies the energy input to the boiler. The solar collector is by-passed during this period by opening the sliding baffle in the upper pump conduit. The lift pump speed is controlled to maintain the desired temperature profiles in the cycle. Sufficient energy is collected and stored to provide 28.5 MW_t continuously over a 24 hour period. This energy is converted to steam at 5.2 MPa, 430°C (750 psia, 800°F) and to an electrical output of 10 MW.

CONCLUDING REMARKS

Industrial production energy requirements are about 40% of the total energy consumed in the United States. The major share of the energy is derived from fossil fuels and significant savings are possible through the use of solar generated process heat coupled with thermal energy storage. DOE/STOR's current activities are directed to the development of generic storage subsystems which will be applicable to solar industrial process heat systems in the intermediate to high temperature range. In-house studies are planned during the current fiscal period to identify technology requirements for SIPH applications. These studies will provide the course for future research and directed development efforts. The ultimate objective of this effort is the demonstration of cost-effective thermal energy storage systems capable of complementing the solar generated process heat source and contributing to energy conservation in the industrial sector.

In addition to the contents of this paper, a panel summary on Storage for Solar Process Heat should also be noted (reference 11). The panel recommended that primary emphasis for the near-term (1980-85) and mid-term (1985-90) should be directed to the transfer of developed industrial process heat storage technologies to solar applications. In support of SIPH applications for the far term (beyond 1990), an aggressive program should be planned and implemented within the next five years to develop the technologies required for the transport of solar process heat to the industrial users (via chemical reactions or hydrogen).

REFERENCES

1. First Annual Thermal Energy Storage Contractors' Information Exchange Meeting, September 8-9, 1976, Lewis Research Center, Cleveland, Ohio.

2. Second Annual Thermal Energy Storage Contractors' Information Exchange Meeting, September 29-30, 1977, Oak Ridge National Laboratory, Gatlinburg, Tennessee.

3. Third Annual Thermal Energy Storage Contractors' Information Exchange Meeting, December 5-6, 1978, Springfield, Virginia.

4. Hausz, W., Berkowitz, B. J. and Hare, R. C., "Conceptual Design of Thermal Energy Storage Systems for Near Term Electric Utility Applications", Volume Two: Appendices - Screening of Concepts DOE/NASA/0012-78/1 Volume 2, October, 1978, General Electric Company.

5. Lundberg, W. L. - Westinghouse Electric Corporation and Wojnar, F. - H. J. Heinz Company, "Applications of Thermal Energy Storage to Waste Heat Recovery in the Food Processing Industry" presented at the 14th Intersociety Energy Conversion Engineering Conference, Boston, Massachusetts, August 5-10, 1979.

6. "Cost Study, Shop Assembly Versus Field Assembly of Heavy Wall Coal Gasifier Reactor Vessels" Final Report FE-2009-13, ERDA Contract E(49-18)-2009, December 1976, Chicago Bridge and Iron Company.

7. "Sodium Sulfate Thermal Storage" Final Report, Contract NAS3-20986, June 1978, Calmac Manufacturing Corporation.

8. Burolla, V. P., Bartel, J. J., "The High Temperature Compatibility of Nitrate Salts, Granite Rock and Pelletized Iron Ore", SAND79-8634, August 1979.

9. Schluderberg, D. C., Thornton, T. A. - Babcock and Wilcox Company, "Moving Bed Heat Transfer for Advanced Power Reactor Applications" presented at Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December 5-7, 1977.

10. Davidson, W. W., etal "Closed Brayton Cycle Advanced Central Receiver, Solar-Electric Power System" Final Report for the period 9/30/70-11/30/78, Volume II, November 1978, Boeing Engineering and Construction Company.

11. "Proceedings of Solar Energy Storage Options Workshop", San Antonio, Texas, March 19-20, 1979, CONF-790328-PI, October 1979.

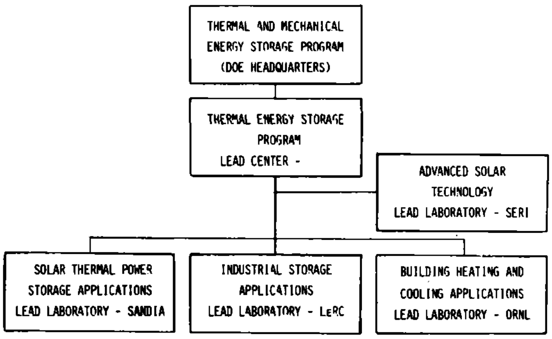

FIGURE 1 - PROPOSED MANAGEMENT STRUCTURE

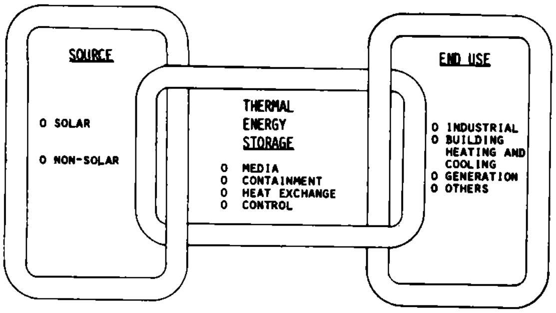

FIGURE 2 - THERMAL ENERGY STORAGE SYSTEM

LIQUIDS		INVESTIGATOR/PROPONENT
o WATER - LOW TEMPERATURE	(250°C)	WESTINGHOUSE/HEINZ-USA
- HIGH TEMPERATURE	(260-360°C)	DR. P. V. GILLI (2)(4,) R/D ASSOCIATES (4) ONTARIO HYDRO (4)
o ORGANIC COMPOUNDS		
- OILS	(200-350°C)	EXXON (4) , McDONNELL-DOUGLAS (4), MARTIN-MARIETTA (4)
o INORGANIC COMPOUNDS - FUSED		
- SALTS	(290-540°C)	ORNL/GENERAL ATOMIC (4) MARTIN MARIETTA (4)
- ELEMENTAL SULFUR	(115-440°C)	DR. A. SELZ (4)

FIGURE 3A - SENSIBLE HEAT STORAGE MEDIA

SOLIDS		INVESTIGATOR/PROPONENTS
o METALS		
- IRON, STEEL	(UP TO 1100°C)	ROCKET RESEARCH (2)
o MINERALS		
- ROCK	(UP TO 550°C)	U. OF MINNESOTA (1- 2)
- SAND	(UP TO 815°C)	JPL (2) . BABCOCK & WILCOX (9)
- TACONITE	(UP TO 550°C)	SANDIA L. L. (8)
o CERAMICS		
- ALUMINA	(UP TO 900°C)	BOEING ENG. & CONSTRUCTION COMPANY (10)
- MAGNESIA	(UP TO 900°C)	BOEING ENG. & CONSTRUCTION COMPANY (1)

FIGURE 3B - SENSIBLE HEAT STORAGE MEDIA

SOLID-LIQUID PHASE CHANGE		INVESTIGATOR/PROPONENT
o NITRATES	(240-340°C)	HONEYWELL INC. (3,4)
o HYDROXIDES	(235-475°C)	COMSTOCK & WESCOTT INC.(1-4)
o CHLORIDES	(370-800°C)	GRUMMAN A. CORP. (1-4),NRL (1-4)
o CARBONATES	(400-890°C)	INST. OF GAS TECHNOLOGY (1-4)
o FLOURIDES	(640-850°C)	ARGONNE NATIONAL LABORATORY (2,3) BOEING ENGINEERING & CONSTRUCTION COMPANY (4)
o METALS	(330-950°C)	U. OF DELAWARE (1-3)
SOLID-SOLID PHASE CHANGE		
o SODIUM SULFATE	(240°C)	CALMAC INC. (7)

FIGURE 3C - LATENT HEAT STORAGE MEDIA

ABOVE GROUND	INVESTIGATOR/PROPONENT
o HIGH PRESSURE TANKS	
- WELDED STEEL	CHICAGO BRIDGE & IRON (6)
- PRESTRESSED CAST IRON VESSEL	DR. P. V. GILLI (2,4)
- PRESTRESSED CONCRETE PRES. VESSEL	ORNL/R. M. PARSONS (4)
o LOW PRESSURE TANKS	
- OIL/ROCK	McDONNEL DOUGLAS (4)
- WATER	WESTINGHOUSE/HEINZ USA (5)
- MOLTEN SALT	ORNL/GENERAL ATOMIC (4)
UNDERGROUND	
o STEEL-LINED CAVITY/ROCK SUPPORT	R/D ASSOCIATES (4)
o STEEL TANK/AIR SUPPORT/UNLINED CAVITY	ONTARIO HYDRO (4)

FIGURE 4 - TES CONTAINMENT

PASSIVE	INVESTIGATOR/PROPONENT
o TUBE/SHELL	GRUMMAN AIRCRAFT CORP. (1-4)
o REFLUX CELL - CANNED MEDIUM	NAVAL RESEARCH LABS (1-4)
ACTIVE	
o DIRECT CONTACT - INTERMEDIATE FLUID	GRUMMAN (3-4) HONEYWELL INC. (3-4)
o MECHANICAL SCRAPER	HONEYWELL (4) , GRUMMAN (3)
o FLUIDIZED BED - ENCAPSULATED MEDIA	BABCOCK & WILCOX (9)

FIGURE 5 - HEAT EXCHANGE - FUSED SALTS

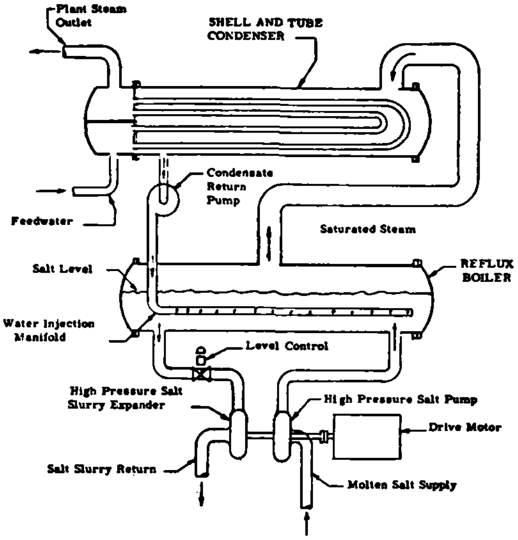

Figure 6 - Continuous Salt Flow Reflux Boiler With Hydraulic Head Recovery

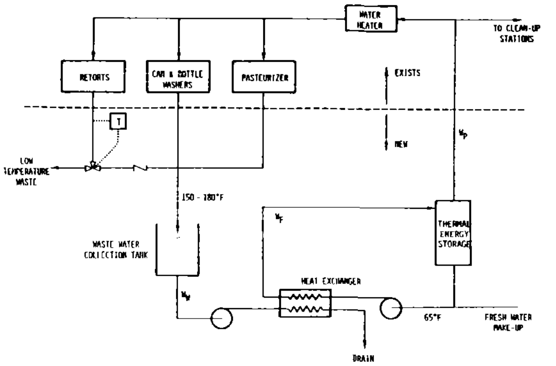

Figure 7 - Heinz USA TES/Waste Heat Recovery System Schematic, Meat Products Building

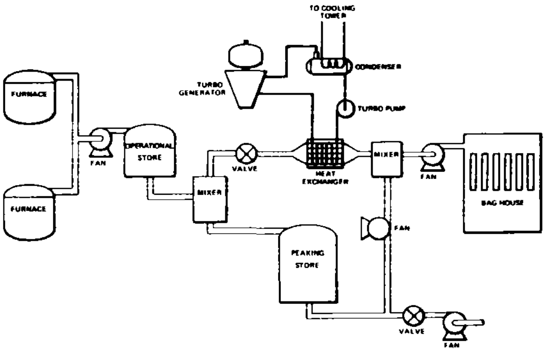

Figure 8 - Steel Arc Furnace Energy Recovery and Storage System

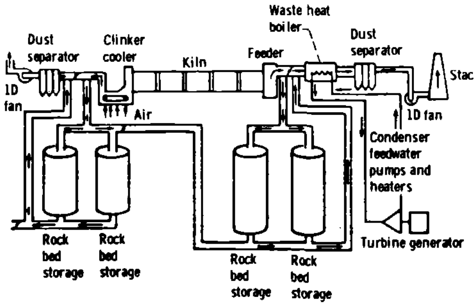

Figure 9. - Cement plant energy recovery and storage system.

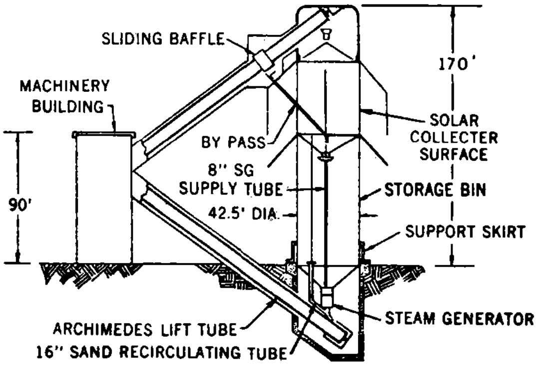

Figure 10 - General Arrangement - Babcock & Wilcox Moving Bed Solar Power Plant

IPH SYSTEM CONFIGURATIONS

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ABSTRACT

An overview of Industrial Process Heating (IPH) system configurations is provided. The selection of a configuration is shown to be affected by the nature of the end process served, the delivery temperatures involved, and the peculiarities of the local plant environment and staffing. Proper identification of valid solar tasks within a given plant is emphasized using Second Law criteria. Particular examples are cited in the discussion of each generic system type.

INTRODUCTION

The energy delivery capabilities of most solar thermal technologies have been shown to be particularly well-suited to the energy needs of industry (1-7). Plant-wide energy needs fall frequently within a range of temperatures easily addressed by solar heating systems. And, unlike many applications in the residential sector, industrial process loads are characteristically year-around operations. This fact contributes to the comparatively rapid amortization of solar industrial process heat (IPH) investments. Potential economies of scale in large IPH projects and the availability of plant operations and maintenance personnel further contribute to a favorable economic picture.

While there are many potential applications of solar energy in the industrial sector, the engineer must exercise care in identifying "valid" or "appropriate" energy tasks for solar thermal technologies within a given plant (8,9). This caveat is prompted by the simple fact that many low temperature tasks in a reasonably large plant can be more economically treated through a reorganization of internal energy flows derived from conventional energy sources. Thermal re-organization within a plant is typified by regenerative or heat reclaim techniques. Interestingly, these techniques frequently pre-empt many of the low temperature solar heating opportunities which are economically preferable from a solar design standpoint. This, in turn, forces the designer to apply his/her solar technologies to higher temperature tasks which cannot be treated by regenerative techniques. Solar system costs and complexity increase accordingly.

The foregoing argument points to the wisdom of a thorough study of plant energetics as a prerequisite to any solar application. This approach helps prevent the designer from overlooking more conventional and economical energy "fixes" when implementing solar technologies. In addition, an understanding of plant energetics helps to establish the "entry-level temperature" which will provide the most useful solar energy at the most attractive cost. It is this entry level temperature which factors heavily into the selection of a system configuration. For this reason, the following subsections outline the necessary steps in identifying appropriate solar heating opportunities within an industrial environment.

CHARACTERIZING ENERGY TASKS WITHIN A PLANT

A comprehensive plantwise survey will catalog individual tasks in terms of both the quantity and quality of the energy required. The former categorization is related to the First Law of Thermodynamics. The latter pertains to the Second Law. The Second Law concept of "energy quality" plays a key role in energy system design. In the case of thermal energy forms, the quality of energy is related to the temperature associated with that energy. Therefore, categorization of tasks by energy quality is a straightforward procedure which uses temperature as the key index.

The need for a measure of energy quality during a survey is evidenced by comparing the two hypothetical energy tasks depicted in Figure 1. In process A, 100,000 Btu/hr is required for a drying operation at 110^{o}F (43^{o}C). In process B, 100,000 Btu/hr is needed for a smelting facility operating at 2500^{o}F (1370^{o}C). While the quantities of energy in each case are identical (First Law equivalence), the energy quality requirements are dramatically different! Interestingly, the quality requirements dictate the flexibility we have in addressing the respective loads. Process A can be supplied from a myriad of energy sources, while process B can be served with only a relative handful of premium energy sources.

Our distinction of energy quality has some powerful philosophical implications as to the "efficiency" with which we use non-renewable fossil fuels. For instance, the use of fossil fuels - with available combustion temperatures of several <u>thousand</u> degrees - to heat water or air to several <u>hundred</u> degrees represents a gross mismatch of source and end-use energy qualities. Analogous energy quality criteria have a very practical impact on the selection of a solar IPH system configuration as well. Preferentially, the solar designer should seek out low temperature (low quality) energy tasks which cannot be addressed by regenerative means. Such tasks can be met by low temperature solar heating systems and components which, because of the inherent thermal properties of solar thermal energy collectors, invariably exhibit increased collection efficiencies for a specific collector type. Higher temperature processes may require more sophisticated technologies and higher costs. Secondly, once a valid energy task has been identified, the solar IPH system should be designed to deliver energy as close to the task temperature as possible. In other words, the designer should strive to match the energy task as closely as possible to the source. This serves to maximize the Second Law efficiency of the operation.

Once the plant survey has been completed, obvious energy conservation opportunities should be given priority in the overall energy program. An aggressive program of component insulation, equipment maintenance, boiler refurbishing, and/or favorable changes in the operational schedule will almost invariably have a more attractive economic return than that of a solar energy alternative. As a next step, a careful examination of the primary energy sources used on site and the flow of this energy through the plant should be undertaken. As mentioned previously, a reorganization of some of the energy flows will often permit one energy task to be satisfied with "waste" energy from another higher quality energy task. Such a rearrangement can eliminate the need for all or part of the primary energy earmarked for the former task.

By way of an example, if Processes A and B depicted in Figure 1 were at the same industrial site, it might be possible to employ "waste" heat from process B to displace all or part of the energy requirements for Process A. This scenario is conceptualized in Figure 2, where it is hypothesized that 75,000 Btu/hr is discharged from the smelting operation at 1500^{O}F (815^{O}C). With the appropriate interfacing, this energy might well address the lower temperature process, effectively displacing 75% of the latter's energy needs from "primary" energy sources. Similar examples include regenerative boiler feedwater heating or combustion air preheat cycles.

An even more ambitious re-organization might be considered in a plant requiring substantial amounts of both electrical and thermal energy. The installation of co-generation equipment (c.f. Figure 3) permits onsite generation of electricity with steam supplied from a fossil-fueled boiler. The discharge steam from the turbine-generator set would then be used for a variety of thermal energy tasks. This scheme is sometimes referred to as a "cascaded energy flow" and is an example of efficient energy management from a Second Law perspective.

Once again, it is important to note that cascaded energy or regenerative schemes sometimes preempt opportunities for low temperature solar applications within the plant. If such regenerative techniques can be applied successfully, the solar system designer will have no choice but to examine the feasibility of addressing the higher temperature (quality) tasks on site.

SELECTION GUIDELINES FOR IPH SYSTEMS

If and when a valid solar/thermal energy task is identified within the plant, the designer can begin to converge on the appropriate system configuration for the task. Several key guidelines should be followed. As mentioned previously, the solar heating system should deliver energy at a temperature as close to the required task temperature as possible. By way of an extreme example, a load center which functions at 120^{O}F ($\sim$50^{O}C) generally should not be served by a concentrating collector array producing steam at, say 350^{O}F ($\sim$180^{O}C). Such an arrangement would be inappropriate in terms of collector efficiency penalties incurred at the unnecessarily high operating temperatures, and the basic tenets of the Second Law in general.

Second, in striving to keep the collector operating temperatures as low as possible, the designer should carefully choose the interface for the solar system and the conventionally fueled backup heating system. There are two basic strategies, shown in Figure 4, which impact collector operating conditions differently. In the "series" configuration, the solar contribution is made at the "front end" of the process where the temperature requirements are frequently low. In this arrangement, the solar/thermal system operates in a pre-heating capacity for the process. This is the preferred alternative in that the array can operate at lower average temperatures and therefore higher collection efficiencies.

If regenerative means are readily applicable and serve to preempt solar pre-heating, the "parallel" configuration may be the only viable solar application. In a parallel configuration, the system must deliver energy at or near the required task temperature. Higher average collector temperatures will be required. To compensate for the higher operating temperatures, a more sophisticated collector will often be needed (e.g., a concentrator), and system complexity and costs are likely to increase.

At this point, the reader should be able to appreciate the advantages and disadvantages of the generic system types to be described in the remainder of this paper. It will become evident that both the system components and design are crucially tied to the character of the energy task, and thus the importance of properly assessing plant needs at the outset will be reaffirmed. The reader will also be alerted to the importance of minimizing heat exchange steps, minimizing or eliminating thermal storage, controlling parasitic power levels, carefully selecting materials, simplifying control systems, and providing adequate collector freeze protection.

AIR-BASED IPH SYSTEMS

Systems which utilize air as the energy transport or "working fluid" have been successfully deployed in the 25-80^{o}C (77-176^{o}F) temperature range (10,11,12,13,14). Non-tracking flat-plate collector arrays are invariably used with open-cycle pre-heating systems enjoying a distinct preference. Favored applications are those in which heated air participates directly in the industrial process. Grain drying and other dehydration processes are representative examples.

Generally speaking, air systems offer a measure of simplicity and cost-effectiveness seldom found in other IPH configurations. Energy transport is accomplished by means of standard, low-pressure ducting networks. The relatively limited consequences of air leakage in these systems serve to relax certain construction criteria and pave the way for site-built collector arrays. Air collectors which are built on-site have been shown to have cost advantages attributable to large scale modularization without attendant transportation penalties (10,12).

Direct-heating air systems eliminate unnecessary heat exchange steps and the need for collector freeze protection. When employed as an energy transport medium, air also avoids many of the corrosion and fire hazard concerns associated with liquid or oil-based circulation systems. And, because of air's low density and specific heat, the total thermal mass of an air-based system can.be low compared to liquid-based systems. The low thermal mass has favorable energy implications during system startup, shutdown, and during other transients.

Unfortunately, air systems are not without disadvantages. The ducting network is more voluminous than comparable liquid-based energy transport systems, suffering from a larger heat loss area and attendant insulation problems. Similarly, the thermal storage for air-based systems often requires more space than that of a liquid storage media, although recent developments in high performance storage media (e.g., latent heat of fusion, salts, or other phase change materials) may eliminate this problem in the near future (15, 16,17). Air-based heat transfer interactions are "thermally weaker" than liquid-based interactions, a fact which strongly discourages unnecessary heat exchange steps.

Importantly, circulation horsepower requirements are also greater for air-based systems. Power is required both to circulate the air through the collector array and to deliver it to the process. The effects can be dramatic -- an air system will typically have horsepower requirements nearly an order of magnitude greater than a comparably-sized liquid system. It is for this reason that air systems work best when the collector array can be located in close proximity to the load center.

In the industrial setting, the circulation power disadvantage can sometimes be muted by the physical layout of the process. If the end process itself requires significant air movement, a solar heating application theoretically need only impose an additional pressure drop caused by the collector array. In this context the marginal increase in power consumption attributable to the circulation of the air through the array is likely to be a small fraction of the total power required for air movement in the process.

The low density and frictional characteristics of air -- primary factors for air's high transport energy requirements -- are amplified as operating temperatures are increased. As system temperatures increase, flow passages in the collector and in the associated transport system must be enlarged. For this reason, air-based collector systems are seldom used in situations which require that the collector array be situated far from the storage and/or load center.

Typical system diagrams for air-based systems appear in Figures 5 and 6. Figure 5 illustrates a fruit and raisin drying application at the Pantaleo drying plant in Central California. Designed jointly by the California Polytechnic State University, TRW Space and Energy Systems, and the Pacific Gas and Electric Company, the system features a 1951 sq. meter (21,000 sq. foot) array of site-built air collectors and a 396 cu. meter (14,000 cu. foot) thermal rock storage (10,12). It is noteworthy that the entire dehydration system employs a regenerative heat recovery unit which performs an initial pre-heating function for the incoming makeup air. The solar heating system further increases the temperature of the air and a conventionally-fired burner supplies the remaining energy, as necessary. This is an example of a series configuration with a regenerative preheating feature.

Figure 6 depicts another series configuration with no thermal storage and no heat recovery. Note that the absence of a thermal storage system considerably simplifies the system schematic, with the array merely providing preheating for combustion air during daylight hours. This particular project features a 1217 sq. meter (13,000 sq. foot) array of Solaron air collectors which serves a drying process in the Goldkist soybean processing facility, Decatur, Alabama (11,13). It should be emphasized that in both examples cited, air heated within the collector array participates directly in the drying process. Further, the array operating temperatures are closely matched to the end-use energy tasks.

Field experience with low-temperature, air-based equipment has been accumulating for over twenty years in the residential sector (18,19). In contrast, large scale IPH Demonstration Projects are relatively new. They have, however, experimentally confirmed the high circulation horsepower requirements of these systems and the need for large, carefullydesigned ducting networks.

The low temperatures and benign working fluid (air) have tended to confirm that materials problems are minimal. Plastic glazings for collectors have perhaps received the most attention, due to potential reductions in weight and cost. However, plastics are known to require careful installation and their long-term stability -- especially under collector stagnation conditions -- has not yet been fully proven (10,12). In contrast, tempered glass, while heavier and more expensive than plastics, has proven to be exceptionally reliable in the low-temperature regimes.

Field experience has also shown that dirt, dust, cooling tower spray, and air-borne corrosives in the industrial environment can reduce array efficiency and/or cause debilitating surface damage to exposed component surfaces. For example, the Goldkist project in Decatur experienced an unexpected and dramatic reduction in glazing transmissivity due to the accumulation of dust-born soybean processing byproducts. When alternately wetted and dried, the coating took on glue-like characteristics and proved to be resistant to normal cleaning procedures (11,13). Additional experience in the industrial environment is required to assess the full impact of cleaning costs on solar system economics (20).

Air-based IPH demonstration projects have also served to identify the potentially formidable cost impact of collector support systems (13). Structural support system costs are certainly not unique to air-based collectors, but it is not uncommon to see these costs equal or exceed that of the collectors themselves. This reality has pointed to the need for more careful attention to the selection of the array site, array modularization, rack details, and optimization of footing placement. Much of the aforementioned work is frustrated by the lack of uniform and definitive guidelines for the calculation of dynamic wind loading (21).

Controls for air-based systems are characteristically simple and reliable. The lack of collector tracking is partially responsible for the streamlined nature of the control system, although the low temperatures and modest safety hazards also tend to introduce simplifications. Importantly, it has been frequently found that the hallmark of control simplicity is the minimization of the number of operating modes. Early designs attempted to incorporate extremely flexible operating formats, with many modal options to accomodate wide variations in environmental conditions and the load served. Newer systems tend to seek a reduction in the number of operating modes, addressing only those modes which appear for the majority of the time. This strategy serves both to reduce system cost and stabilize operation.

Another major step in the simplification of IPH systems involves the elimination of thermal storage by appropriately sizing the array with respect to the load served.

LIQUID-BASED SYSTEMS FOR LOW TEMPERATURE APPLICATIONS BELOW 100°C

While air-based systems offer some unique advantages in the low temperature regime, liquid-based systems are also popular for low temperature tasks. These systems typically employ non-tracking flat plate or evacuated-tube collectors, and use some form of liquid as the primary energy transport medium. Aqueous solutions are the most popular working fluids, although oils and silicones have been used with success.

There are a myriad of possible configurations for liquid-based systems. For obvious reasons, those systems which can directly heat the process material in the collector array have substantial thermal advantages. Such a system is depicted in Figure 7. It is unfortunate that few such direct heating applications occur in practice. For direct heating, the working fluid must be chemically compatible with the collector flow passages and piping, must not foul the heat transfer surfaces, must have reasonable viscosity and vapor pressure characteristics, and must be immune to freezing. Few process fluids meet all of these criteria, although water of reasonable quality meets all but one -- that of freeze immunity.

Since process hot water is a common industrial requirement, there are a number of systems in operation which rely on the direct heating principle. In climates where air temperatures never fall below around 7°C (45°F), freeze protection is unnecessary. In colder climates, including most of the continental United States, means must be found to prevent the collectors from freezing under conditions of cold outdoor temperatures and/or night-time radiant effects. Freeze protection in direct water heating systems is accomplished by recirculation of stored thermal energy, recirculation of fluid heated by a supplemental energy source, or by draining the collector array during freezing conditions. The first two system configurations are schematically identical to that shown in Figure 7, but are recommended only in climates where freezing conditions are extremely rare (e.g., the extreme southern portions of the United States). The latter system configuration is depicted in Figure 8, and is appropriate if the array layout is conducive to reliable automatic drain and fill operations. In certain higher-temperature applications, the introduction of oxygen during drain/fill operations may adversely impact system corrosion rates.

In many cases it is impractical to run the process material through the collector array. High viscosity oils, flammable substances, corrosive materials, and certain gases are poor candidates for a collector working fluid. Many process water heating systems do not employ direct heating either, due to severe freeze potentials or poor water quality. Such situations generally require the use of a two-fluid, heat exchange system such as depicted in Figure 9. The material circulating through the collector array is either an aqueous anti-freeze mixture or, in some cases, a non-aqueous solution such as silicone or a hydrocarbon-based oil. Such systems provide positive freeze protection in all forms of weather without the need of auxiliary energy supplies to institute "active" freeze protection measures. Heat exchange systems also provide a controlled chemical environment for the primary circulation loop -- often a key to longer collector life.

An important subcategory of heat exchange systems sometimes appears in the form of a liquid/air hybrid system. These systems feature a liquid-based collector loop which, in turn, provides energy to an air stream via a liquid-to-air heat exchanger. This approach is favored when the required delivery temperatures exceed those easily obtained by flat plate, air-based collectors, or when the distance between the load served and the collector array is great. The Gilroy Foods Solar Project in Gilroy, California (22, 23) and the kiln-drying facility in Canton, Mississippi (24) serve as examples of this design philosophy.

Regrettably, the heat exchange process introduces irreversibilities which degrade the performance of the entire system. Depending on the heat exchange design, energy losses are typically on the order of 5-15% as compared to a direct heating system. In addition, the working fluid must be periodically checked for its chemical quality. Also, agents such as silicone and oils require higher pumping horsepower than do aqueous solutions (though still much less than comparably-sized air systems). In most cases, this pumping horsepower penalty is attributable to the lower specific heat of certain anti-freeze or oil-based materials, requiring higher circulation to provide the same energy transfer rates. Viscosity effects can also be pronounced, especially during start-up conditions at low temperatures. Occasionally, a separate, low-flow, high-head pump is used to establish flow during a cold start-up (25).

Field experience with low temperature liquid-based systems parallels that of their air-based counterparts. Materials considerations, array support costs and controls experience have been almost identical. Perhaps the most significant variation in the performance of these systems has been in regard to collector freeze protection. There has been an incident of freeze damage in the IPH program, attributable in one case to the omission of a simple check valve in the collector loop (28). These experiences serve to alert future designers to the effects of night time radiation losses and low ambient air temperature, not to mention the dire consequences of inadequate system freeze protection.

As with air-based systems, surface contamination of liquid-based arrays has been observed and active cleaning is generally required. Additionally, there have been instances of damage to thermal insulation in both the collector and manifolding systems due to inadequate flashing details (26,27).

In summary, low temperature liquid-based IPH systems are characterized by conventional, low-pressure piping systems with modest materials requirements. Due to the absence of collector tracking, the control systems are generally straightforward. If the load is large compared to the collected solar energy, thermal storage can be minimized or eliminated altogether, thereby introducing further control simplification.

The number of privately-funded and/or government-assisted low temperature IPH projects is impressive. Many are referenced in these proceedings (28,29,30,31).

MEDIUM TEMPERATURE IPH SYSTEMS (100-300°C)

An even greater fraction of the United States industrial energy consumption falls within the temperature range of 100-300°C (212-572°F). The end uses are innumerable, although the energy delivery medium is often low or moderate pressure steam. This elevated temperature range all but eliminates the competitiveness of flat-plate collector technology, and quickly propels the designer into the realm of the evacuated-tube or tracking collector technologies. Parabolic line-focusing or Fresnel-type collectors are the most popular types within the tracking class. Invariably overall design complexity, materials, and safety problems are increased.

Liquid-based collector loop systems dominate this temperature range due to their "compactness" and relatively low circulation power requirements. The problems associated with high temperature piping systems, flexible or rotary connections (required by tracking collectors), and sophisticated control systems become paramount in the designer's work. The question of freeze protection remains and must be addressed in the usual ways.

Medium temperature systems frequently employ heat exchangers. The heat exchanger serves not only to chemically isolate the collector array from the process, but also enables the designer to select a low vapor pressure material for the collector circulation loop. By means of a heat exchanger, a system could generate 288°C (550°F) steam without exposing the collector to $7x10^6$ N/m^2 (1000 psia) pressures required if the steam were being generated directly. In many such applications, oil-based media are chosen for the collector loop and system pressures can be reduced by an order of magnitude. This strategy enjoys some cost savings in the main circulation loop piping and also provides a positive means of freeze protection. On the other hand there are thermal penalties associated with the heat exchanger and non-aqueous solutions have been notorious for small. persistent leaks. Some chemically degrade with use.

An example of a heat exchanger-based system which is used to generate low pressure steam is given in Figure 10. Note that the primary loop heat exchanger is immersed in a simple steam-drum boiler. This configuration permits the use of a standard evaporative boiler coupled with a relatively low pressure collector circulation loop. Projects such as the planned Lone Star Brewery system in San Antonio, Texas (34), the West Point Pepperell Martex Towel mill in Fairfax, Alabama (35,36) and the Home Laundry Project in Pasadena, California (37) are all examples of heat-exchange design approaches.

Figure 11 illustrates an alternative for producing steam at low to medium pressures. Known as a "direct-flash" process, liquid conditions are maintained in the receiver tubes of the collector array. Vapor production occurs via a physically distinct flashing process followed by a liquid vapor separation in a pressure vessel. The vapor is delivered to the process and the remaining liquid is recirculated to the collector array.

This approach avoids the complexities of a two-loop system and the thermal penalties of a heat exchanger. However, it requires that the collector tubes and associated piping withstand the high pressures associated with elevated water temperatures. A pump with high head is required to prevent the fluid within the collectors from boiling prematurely. Examples of direct flash processes include the Stauffer Chemical system proposed for Henderson, Nevada (38), the ORE-IDA Foods System earmarked for Ontario, Idaho (39), and the recently completed 1070 sq. meter (11,520 sq. foot) Johnson and Johnson facility in Sherman, Texas (32,33).

Several proposals have been advanced to allow steam formation within the collector receiver tubes themselves. To date, this technique has not been tested in any full-scale projects because of the unknown repercussions of vapor formation in horizontal receiver tubes. The technique itself has considerable precedent in normal boiler technology, where it is more frequently associated with vertical tubes. It has been suggested that this concept be pursued on a research or demonstration level, perhaps in conjunction with a thermosyphon configuration (21). An off-horizontal array would be similar in concept to a "chemical reboiler" with nearly identical heat flux rates.

Generally, medium temperature IPH systems have been plagued by excessive costs, materials problems, component damage attributable to thermal expansion, and deficiencies in the tracking controls. Most of these difficulties can, in turn, be directly traced to the higher operating temperatures. Medium temperature systems also experience greater thermal inefficiencies during startup and shutdown due to the increased levels of stored energy associated with the operating system. Field experience has tended to confirm many of the aforementioned problem areas. With regard to materials, absorptive coatings for concentrator receivers have been found to degrade and/or separate mechanically (30). Inadvertent focusing during no-flow or "stagnation" conditions has caused several such failures in concentrating collectors, while others were simply victims of high temperatures over a period of time. More advanced coatings recently have been developed, most notably a new black-chrome selective surface advanced by SERI/SANDIA and said to be stable at temperatures well above the previous limiting value of 300^{o}C (575^{o}F).

Reflective materials for concentrating collectors have also received considerable attention. Lightweight acrylic and aluminized-mylar films have been historically popular and have proven to be relatively stable in many environments. However, isolated cases of severe surface degradation have been observed in certain industrial environments (21). Repeated cleaning adversely affects these polymeric materials (20,21,40). Thermally formed and "micro-sheet" glasses with back-silvering are now being released on an experimental basis by SERI to concentrator manufacturers. In either form, the glass is expected to have greater longevity in the industrial surroundings and exhibit higher specular reflectivity than the plastics currently in use (40).

Operational data have confirmed that, like flat plate collectors, concentrating collectors require periodic cleaning. There is indication that reflector cleanliness is even more critical than glazing cleanliness in flat plate collectors. Reflector surfaces have been shown to respond well to a high pressure water rinse. Frequently, the magnitude of the contamination problem is less with tracking collectors, in that they will generally "stow" during non-sunlight hours. The protective position eliminates one of the major contributors to tenacious contamination films -- that of the morning and evening dew deposits common to collectors which continuously face the sky. The stow capability present in most of the tracking collectors also can be used to shield sensitive surfaces from abrasion due to wind-borne particles.

Control systems for medium temperature IPH configurations are generally more sophisticated due to the need for collector tracking. Additionally, the need to adequately address "off-design" conditions such as startup, shutdown, or alarms is made pressing. These conditions tend to be of more concern because of the temperatures involved, the attendant safety ramifications, and the potential for equipment damage. Industrial-grade microprocessor controls are becoming a common solution as they offer the designer a greater degree of flexibility and the potential for field adjustments. However, their inherent deficiencies in fail-safe configurations must be considered (25).

Control instabilities have arisen under conditions of varying insolation. Nominally sunny days with patchy cloud cover have caused the most problems. The sudden drop in insolation caused by a passing cloud has caused tracking systems to disengage for the remainder of the day. And, all too frequently, tracker electronic adjustments have been troublesome. Rapid variations in insolation tend to throw the operating process into chaos as well. Stability problems have also arisen early in the morning or late in the evening when insolation levels are low. Fortunately, control refinements are being developed rapidly. Improved circuitry is now available to compensate for low insolation conditions and to accomodate rapid variations in cloud cover. Tracking subsystems have been provided with anticipators to compensate for interruptions in the direct beam components (21,41,42).

There are several notable examples of medium temperature IPH systems described in these proceedings and elsewhere (43,44,45,46). To date, most have been funded under the auspices of the USDOE IPH Demonstration Program, although future projects are to be guided by SERI.

SYSTEM COMPATIBILITY WITH THE PLANT

The previous sections have attempted to outline the generic characteristics of certain IPH systems. While the unique aspects of each system configuration were highlighted, there are some design constraints shared by all systems. Most notably, the designer should fully comprehend the nature of the industrial environment in which the system is to be placed. For one, the experience of the resident plant maintenance personnel must be factored into the design. In many cases, certain types of systems (e.g., oil-based systems or high pressure water systems) must be excluded due to the lack of plant personnel trained in these technologies. Similar criteria apply to the selection of control equipment which will interface with the plant's existing controls network. The equipment should be as compatible as possible with the existing plant facilities (i.e., one should refrain from specifying pneumatic controls in a plant which has historically used electronic controls.)

Systems designers and manufacturers should also be aware of the corrosive microclimates within many industrial plants. The impact of corrosives is not limited to collector hardware, but extends to the more mundane elements of collector support members, piping, weldments, and other exposed surfaces. DOE and SERI-funded projects now require that critical materials be subjected to an exposure test in the plant environment during the system design phase. This is an attempt to provide an early indication of potential materials problems.

Interestingly, it may well be that one of the foremost challenges to future IPH programs will be one of upgrading the equipment and solar design expertise to match the high standards historically demanded by the industrial community.

SUMMARY

A wide variety of IPH solar/thermal system configurations have already been explored under the auspices of the USDOE and SERI. A great deal has been learned from these programs and the future promises to reveal better and more cost effective means to integrate solar/thermal technologies in the industrial environment.

In specific terms, data acquisition programs just now being implemented will serve to validate calculated system performance. Component lifetimes, materials performance, and maintenance histories will be established. The aforementioned information will help establish standardized design criteria for future IPH installations. With this growing data base, cost reductions will likely be realized and an industrial support infrastructure will begin to flourish. Carried to fruition, the overall effort has the potential of making significant contributions to our industrial energy budget.

ACKNOWLEDGEMENTS

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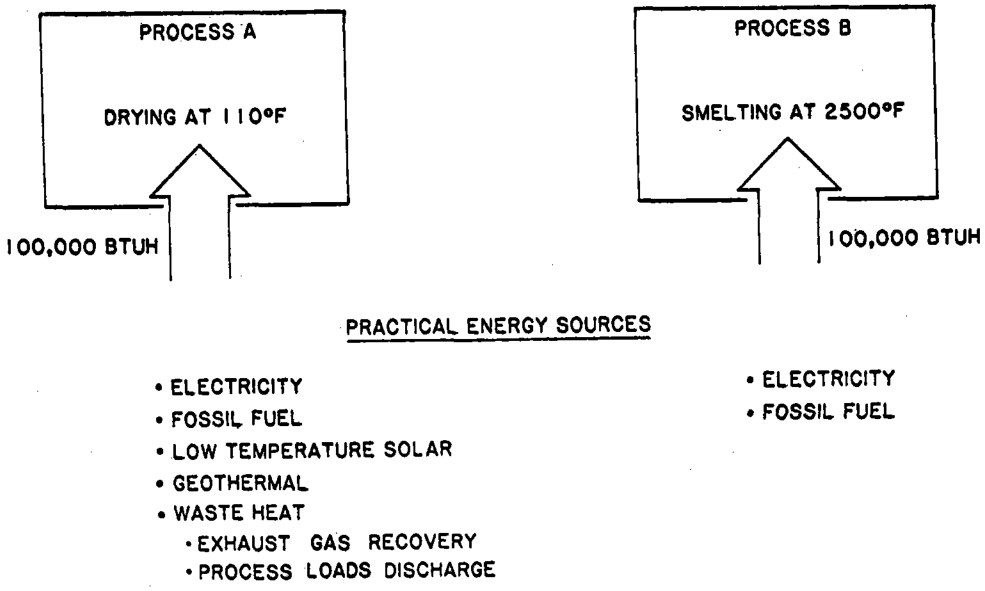


FIGURE 1 Two processes with First Law Equivalence

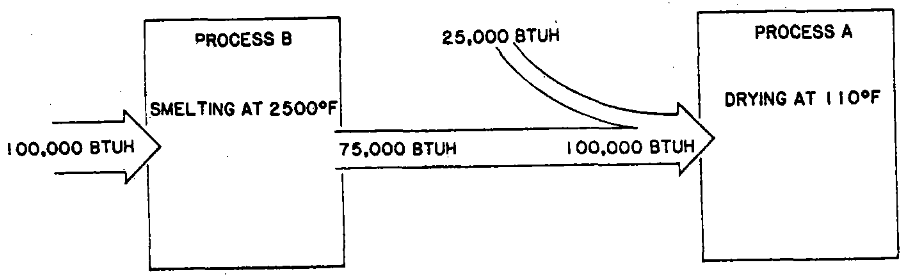


FIGURE 2 Utilization of waste heat to displace primary energy sources

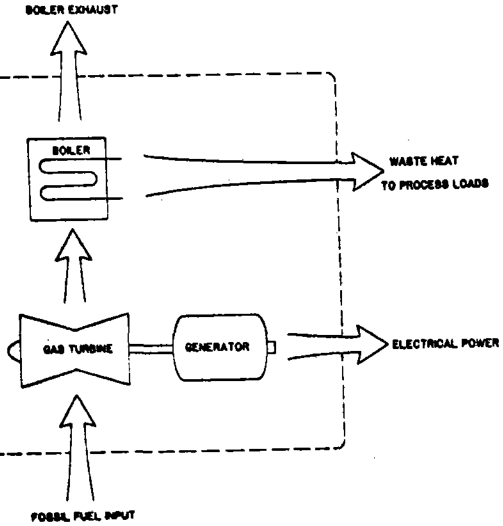
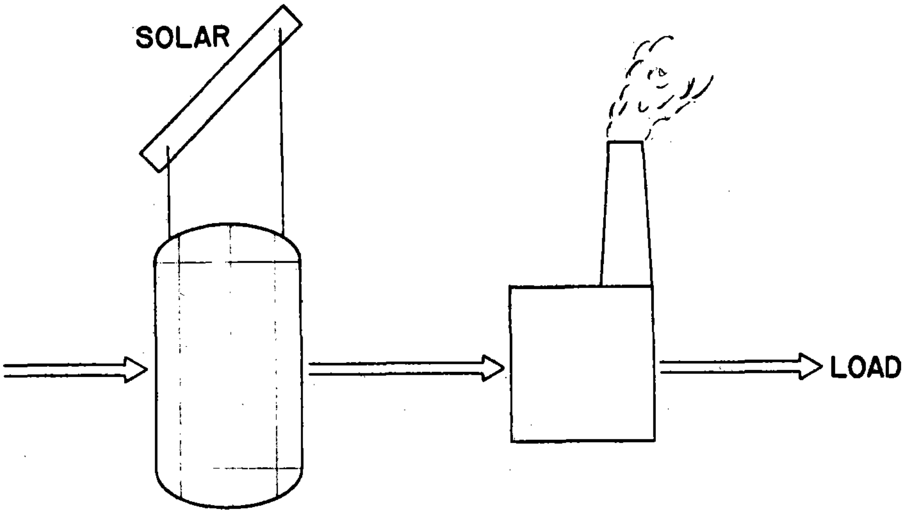
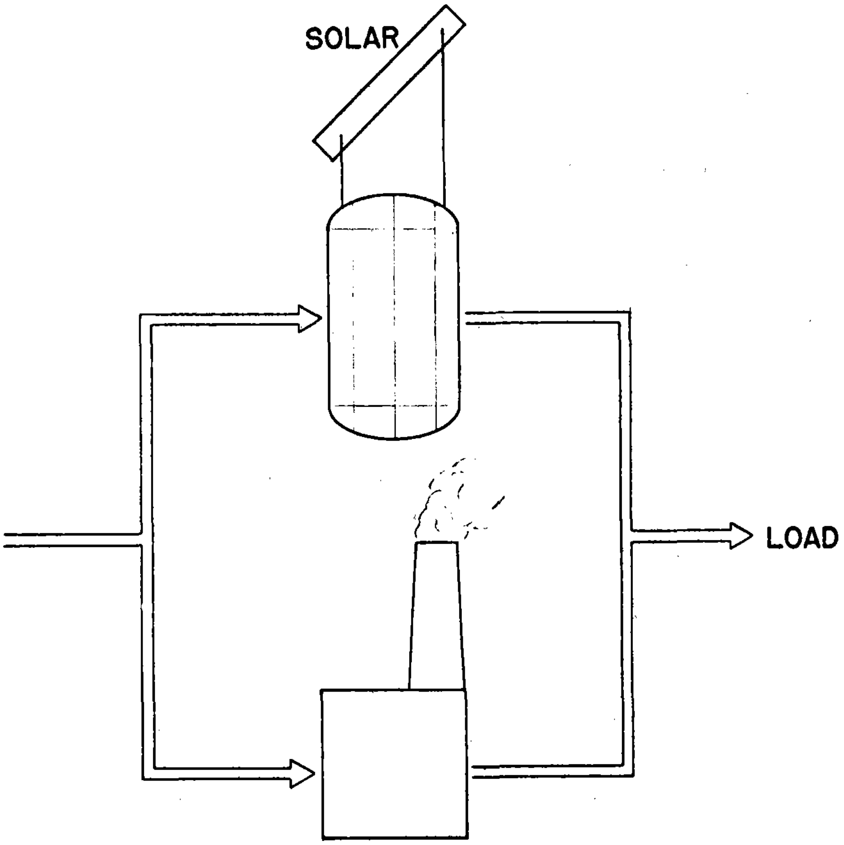


FIGURE 3 A cogeneration scheme



SERIES



PARALLEL

FIGURE 4 Series and parallel solar configurations

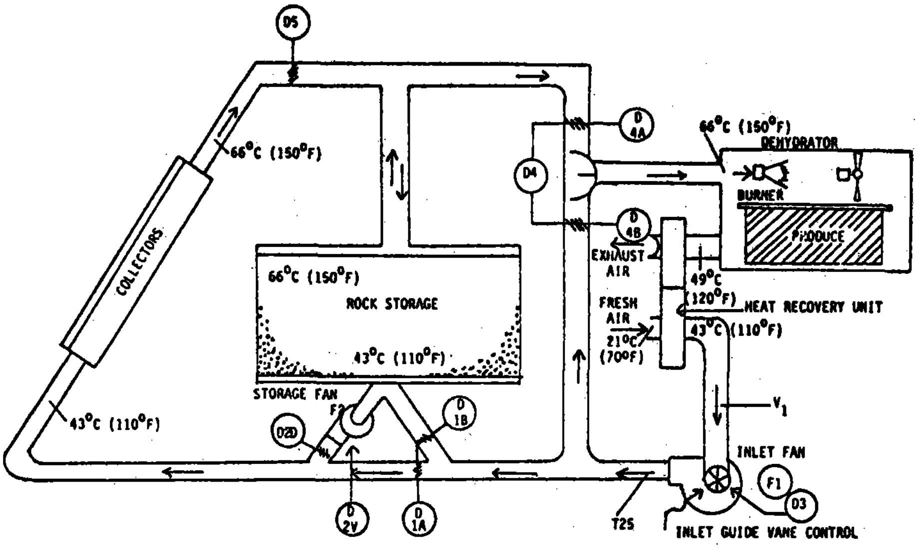


FIGURE 5 Schematic for air-based system for Pantaleo drying plant (from Ref. 10)

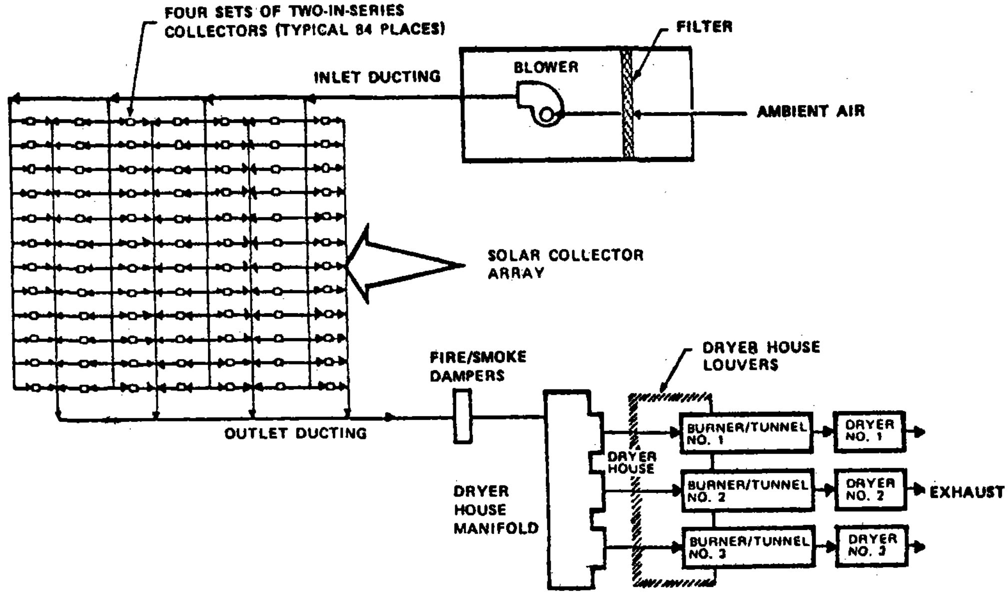


FIGURE 6 Schematic of air-based system for Goldkist soybean facility (from Ref. 11)

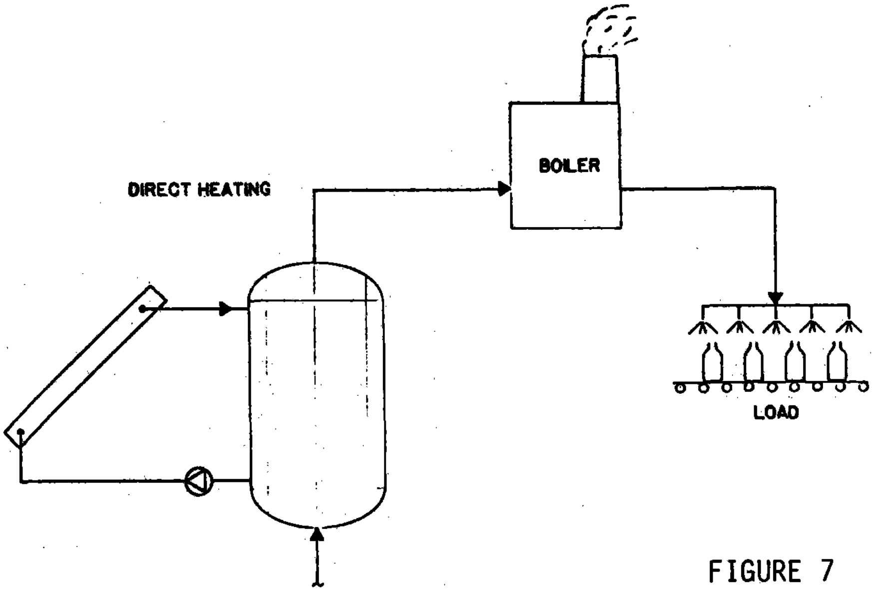


FIGURE 7

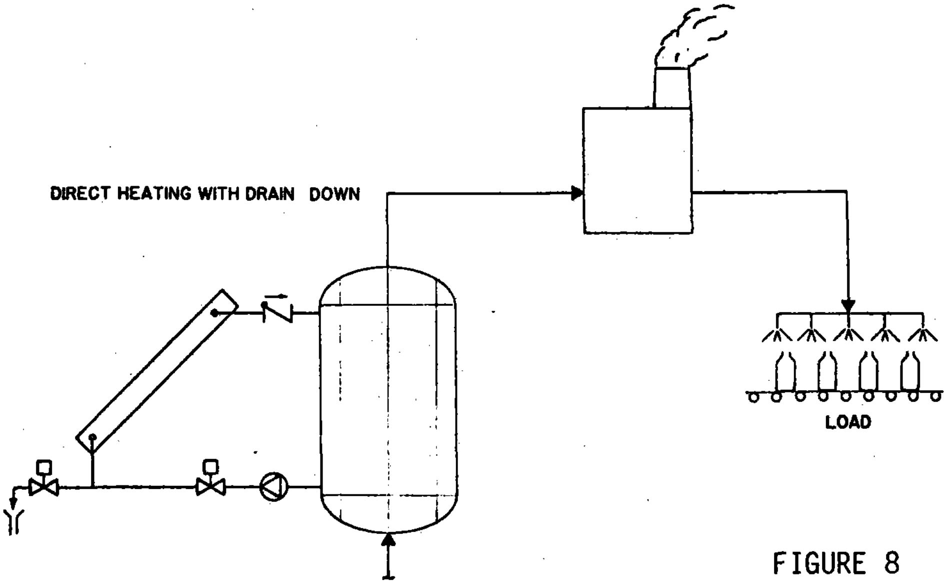


FIGURE 8

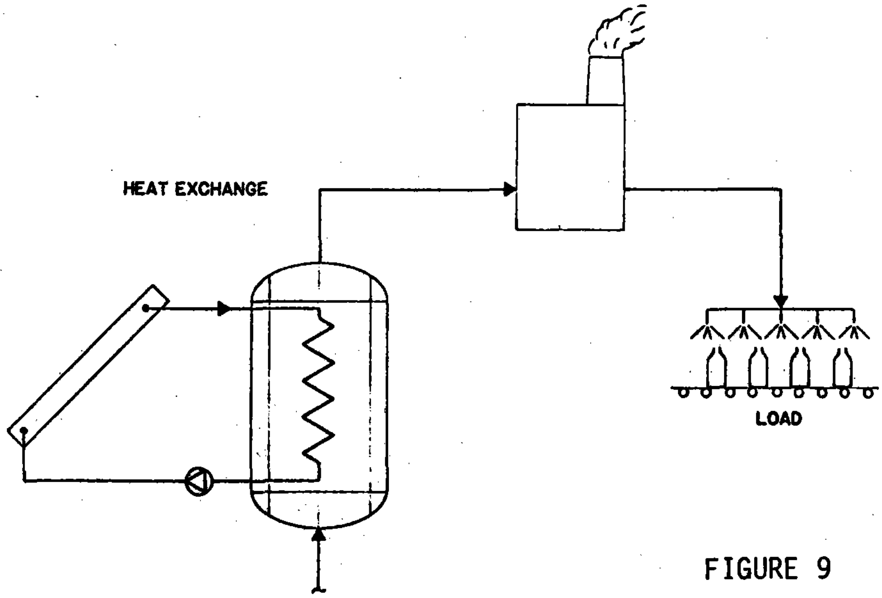


FIGURE 9

Heat Exchange System

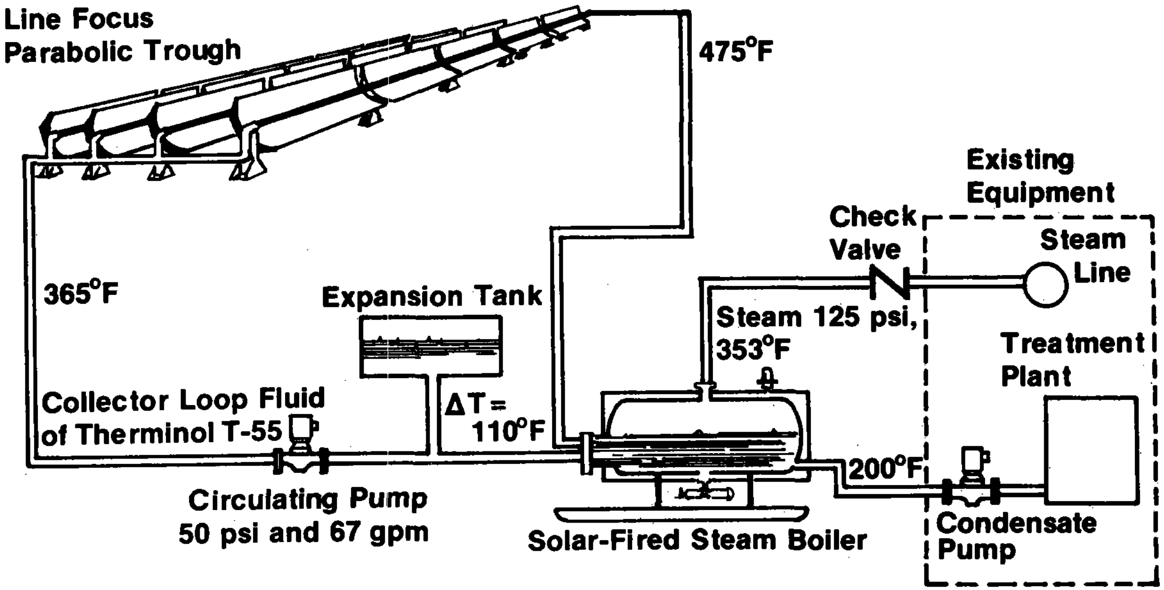


FIGURE 10

Flash System

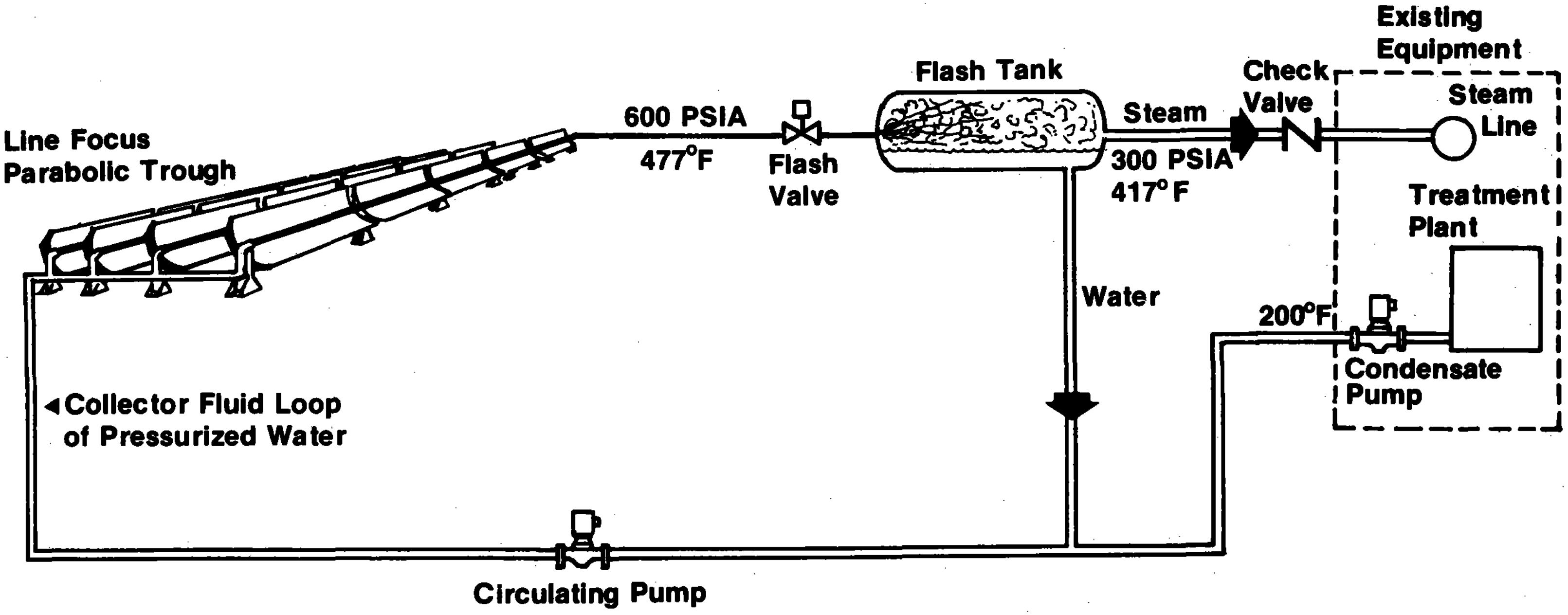
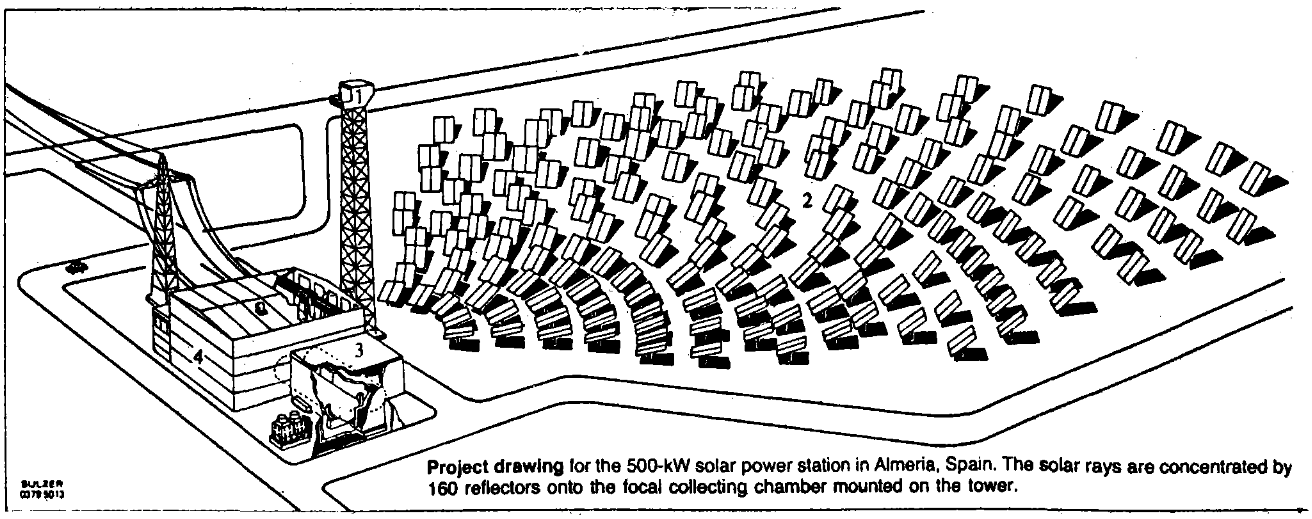


FIGURE 11



Project drawing for the 500-kW solar power station in Almeria, Spain. The solar rays are concentrated by 160 reflectors onto the focal collecting chamber mounted on the tower.

Figure 12.

REFERENCES

1. Fraser, M.D., *Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat*, InterTechnology No. 00028-1, InteTechnology Corpoation, Warrenton, Virginia, (1977).
2. Hall, E.H., *Survey of the Applications of Solar Thermal to Industrial Process Heat*, ERDA TID-27348-1 Battelle Columbus Laboratories, (1977).
3. U.S. Department of Energy, *Solar Energy for Agricultural and Industrial Process Heat, Program Summary*, DOE/CS-0053, (September 1978).
4. Solar Energy Research Institute, *Proceedings: Solar Industrial Process Heat Conference*, Denver, Colorado, (October 1978).
5. Bennington, G., et al., *Solar Energy: A Comparative Analysis to the Year 2000*, MTR-7579, The MITRE Corporation, McLean, Virginia, (March 1978).
6. Solar Energy Research Institute, *Putting the Sun to Work in Industry*, SERI/SP-34-175, SERI, Golden, Colorado, (March 1979).
7. Jet Propulsion Laboratory, *Solar Energy for Process Heat. Design/Cost Studies of Four Industrial Retrofit Applications*, JPL 78-25, Pasadena, California, (April 1978).
8. Casamajor, A. and Wood R., "Limiting Factors for the Near-Term Potential of Solar Industrial Process Heat", *Proceedings: Volume 1. Solar Industrial Process Heat Conference*, SERI/TP-49-065, SERI, Golden, Colorado, (October 1978).
9. Brown, Kenneth C., et al., *End Use Matching for Solar Industrial Process Heat*, SERI/TR-34-091, Solar Energy Research Institute, Golden, Colorado, (1979).
10. Carnegie, E.; Pohl, J., and Niles, P., "Agricultural Industrial Hot Air System", *Proceedings: Volume 1. Solar Industrial Process Heat Conference*, SERI/TP-49-065, SERI, Golden, Colorado, (October 1978).
11. Guinn, G. "Process Drying of Soybeans Using Heat from Solar Energy", *Proceedings: Volume 1. Solar Industrial Process Heat Conference*, SERI/TP-49-065, SERI, Golden, Colorado, (October 1978).
12. Carnegie, E., Niles, P., and Stine, W., "An Analysis of the Operation of an Industrial Drying Solar System", *Proceedings: Solar Industrial Process Heat Conference, Oakland 1979*, SERI, Golden, Colorado, (Scheduled for Publication 1980).
13. Hall, B., "Solar Augmented Soybean Drying", *Proceedings: Solar Industrial Process Heat Conference, Oakland 1979*, SERI, Golden, Colorado, (Scheduled for publication 1980).

14. Smith, C., "Solar Supplement to Laundry Drying", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

15. Kreith, F., Wyman, C., Castle, J., A Review of Collector and Energy Storage Technology for Intermediate Temperature Applications, SERI/TP-34-366, Solar Energy Research Institute, Golden, Colorado, (March (September 1979).

16. Wyman, C., Thermal Energy Storage for Solar Applications: An Overview, SERI/TP-34-089, Solar Energy Research Institute, Golden, Colorado, (March 1979).

17. Gintz, J., Technical and Economic Assessment of Phase Change and Thermochemical Advanced Thermal Energy Storage Systems, EPRI Report EM-256, Electric Power Research Institute, Palo Alto, California, (1976).

18. Lof, G., "Heating with Solar Heated Air", ASHRAE Journal, (October 1963).

19. Lof, G., and Tybout, R., "Solar Home Heating", Natural Resources Journal, (April 1970).

20. Lukens, L., and Schimmel, W., "Effects of Cleaning Costs on Process Heat from Line Focus Solar Collectors", Proceedings: Solar Industrial Heat Process Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

21. Stauffer Chemical Company/Pacific Sun Incorporated, Phase I: Analysis and Design Report, DOE Contract EM-78-C-03-1882, (October 1979).

22. Graham, B., Sierer, P. and Powell, D., "Application of Solar Energy to the Dehydration of Onions and Garlic: Gilroy Solar Project -- Initial Operation and Evaluation", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

23. Graham, B., Saarlas, M., and Sierer, P., "Application of Solar Energy to the Dehydration of Onions", Proceedings: Volume I. Solar Industrial Process Heat Conference, SERI/TP-49-065, SERI, Golden, Colorado, (October 1978).

24. Robertson, S., and Merrifield, D., "Solar Heated Lumber Kiln", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

25. Su, W. and Castle, J. State-of-the-Art Solar Control Systems in Industrial Process Heat Applications, SERI/TP-39-240, Solar Energy Research Institute, Golden, Colorado, (July 1979).

26. Trice, J. Cohen, A., "Commercialization Aspects of Solar Process Hot Water Systems for the Textile Industry", Proceedings: Volume I Solar Industrial Process Heat Conference, SERI/TP-49-065, SERI, Golden, Colorado, (October 1978).

27. Trice, J., Herz, J., and Burns, R., "Operational Results of the LaFrance, South Carolina Solar Process Hot Water System", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden Colorado, (Scheduled for Publication 1980).

28. Wilkening, H. "Solar Industrial Process Hot Water for Concrete Block Manufacture", Proceedings: Solar Industrial Process Heat Conference, Oakland, 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

29. Youngblood, S., and Swartz, D., "One Year of Operating Experience at the Campbell Soup Solar Hot Water Facility", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

30. Willening, H.A., "Solar Industrial Process Hot Water for Cement Manufacture", Proceedings: Volume I. Solar Industrial Process Heat Conference, SERI/TP-49-065, Solar Energy Research Institute, Golden, Colorado, (October 1978).

31. Vindum, J. and Bonds, L., "Solar Energy for Industrial Process Hot Water", Proceedings: Volume 1. Solar Industrial Process Heat Conference, SERI/TP-49-065, Solar Energy Research Institute, Golden, Colorado, (October 1978).

32. Youngblood, S., "Solar Energy for Industrial Process Steam", Proceedings: Volume 1. Solar Industrial Process Heat Conference, SERI/TP-49-065, Solar Energy Research Institute, Golden, Colorado, (October 1978).

33. Boeck, W. and Harper, R., "Construction of a Solar Industrial Process Steam System for the Johnson and Johnson Manufacturing Plant", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

34. Deffenbaugh, D., "Solar Production of Industrial Process Steam for the Lone Star Brewery", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

35. Mitchell, P. "Textile Drying at Westpoint Pepperell Using Solarized Can Dryers", Proceedings: Volume I. Solar Industrial Process Heat Conference, SERI/TP-49-065, Solar Energy Research Institute, Golden, Colorado, (October 1978).

36. Mitchell, P.D., "Textile Drying at Westpoint Pepperell Using Solarized Can Dryers", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

37. Eldridge, G., Roos, C., and Goranson, G., "The Industrial Process Heat Demonstration at the Home Laundry, Pasadena, California", Proceedings: Volume I. Solar Industrial Process Heat Conference, SERI/

TP-49-065, Solar Energy Research Institute, Golden, Colorado, (October 1978).

38. Kast, M., Ortiz, P., and Whitehouse, H., "Solar Production of Industial Process Steam for the Stauffer Chemical Company", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

39. Cherne, J., "Solar Production of Industrial Process Steam for Potato Frying", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

40. Gee, R., Gaul, H., and Kearney, D., "Long Term Average Performance Benefits of Parabolic Trough Improvements", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

41. Treadwell, G., "Parabolic Trough/Flat Plate Collector Performance Comparison", SAND Report 79-1296A and Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

42. Carlton, R., "Reliable Commercial Tracker for Line-Focusing Collectors" Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

43. Kull, J., Matteo, M., and Yasuda, A., "Design and Analysis of a Solar Industrial Process Heat System for ERGON, INC.", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

44, Gupta, G., and Bhayana, G., "Systems Analysis of a Solar Industrial Process Steam Concentrating Systems", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

45. Trice, J., "Solar Production of Low Pressure Steam for Processing Orange Juice", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

46. Trice, J., and Cohen, A., "Solar Production of Low Pressure Industrial Process Steam for Processing Orange Juice", Proceedings: Solar Industrial Process Heat Conference, Oakland 1979, SERI, Golden, Colorado, (Scheduled for Publication 1980).

QUESTIONS

Question: You stated in your presentation that Central Receivers are only useful for generating 1000 degree steam to produce electricity. Since a central receiver produces a high flux density why can't it be used to produce thermal energy at other temperatures for thermal applications and for producing fuels and chemicals?

Answer: I did not intend to rule out the direct application of high temperature thermal energy from central receivers for those processes that require it. If high temperature thermal energy is needed for a particular process (e.g. chemical processing), the central receiver system can certainly provide that energy.

Question: What is the source for your statement regarding the role of central receiver systems for IPH?

Answer: I presume you are refering to my comments on the use of a central receiver system to both generate electricity for a nearby community or industrial facility and supply waste heat to the same community for process heating.

While I have no specific source for my statement, it is not a particularly new concept. Such schemes have been frequently proposed for large-scale, fossil-fueled electrical generation plants and often employed in smaller-scale facilities. The solar receiver approach solves the problem of community acceptance of such a "total energy" scheme, in that the plant itself is likely to draw few environmental objections. In contrast, it would be difficult to envision a warm reception for a coal or nuclear-fired power plant in such close proximity to the end-users.

Economics Session

ECONOMIC ANALYSIS OF SOLAR INDUSTRIAL PROCESS HEAT SYSTEMS: A METHODOLOGY TO DETERMINE ANNUAL REQUIRED REVENUE AND INTERNAL RATE OF RETURN

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ABSTRACT

To permit an economic evaluation of solar industrial process heat systems, we have developed a methodology to determine the annual required revenue and the internal rate of return. In this paper we first briefly outline the methodology, presenting the basic cost equations. We then apply the methodology to determine the level of government tax and loan incentives that will probably be necessary to make solar IPH systems economically attractive to industry.

INTRODUCTION

The title of this paper is the same as the title of a report, UCRL-52814, August 17, 1979, issued by the author and K. C. Brown of the Solar Energy Research Institute. The report first provides a format to estimate an industrial solar system's installed cost, anual operating and maintenance expenses, and net annual solar energy delivered to the process. Then an expression is presented that gives the annual required revenue and the "price" of solar energy. The economic attractiveness of the solar investment can then be determined by comparing the price of solar energy with the price of fossil fuel, both expressed in levelized terms. This requires calculation of the internal rate of return on the solar investment. The report also presents four different methods that are used to calculate a payback period.

OUTLINE OF METHODOLOGY

The annual required revenue for solar generated energy is the total amount of revenue that must be set aside each year to provide that energy. This amount must cover the return on the equity portion of the solar investment, principal and interest payments on the debt portion of the investment, state and federal income taxes, property tax, insurance premium, operating and maintenance costs, and expected major repairs and component replacement.

An expression for the levelized required revenue, C_s, in current dollars is derived in UCRL-52814 and reproduced below:

$$\frac{C_s}{I} = \mathrm{OMPI} + \frac{\mathrm{CRF(R,N)}}{1-\tau}\Bigg[(1-f) + f(1-\tau)\frac{\mathrm{CRF(r,LP)}}{\mathrm{CRF(R,LP)}} + \frac{f\tau}{1+r}\,\frac{\mathrm{CRF(r,LP)} - r}{\mathrm{CRF(R'',LP)}}$$

$$- \frac{\mathrm{TC}}{1+R} - \tau \cdot \mathrm{DEP} + \left(\frac{1+g}{1+R}\right)^{t_c} \cdot m(t_c) \cdot \left(1 - \mathrm{TC} - \tau \cdot \mathrm{DEP}\right) - \left(\frac{1+g}{1+R}\right)^{N} S\Bigg] \qquad (1)$$

The definition of all terms in Equation 1 is given in Table 1. The ratio, C_s/I, we refer to as M or the "M-factor." It is analogous to the levelized fixed charge rate used by utilities to determine required revenue. It is the single number that, when multipled by the initial solar investment, gives the levelized required revenue expressed in current dollars. Tabular values of M are presented in UCRL-52814 as well as graphical values for two different baseline solar sytems.

If the annual amount of solar energy delivered and utilizied at the point-of-use is E_s, then the levelized price* of solar energy is given by

$$P_s = \frac{C_s}{E_s} = M \cdot \frac{I}{E_s}\left[\$/\mathrm{MBTU},\ \$/\mathrm{kWh},\ \$/\mathrm{GJ}\right] \qquad (2)$$

It is suggested that, in using Equation 2 to determine a base levelized price for solar energy, the discount rate R be set at the average company market earning rate on investments, based on recent and current performance. Historic market earning rates for many large industries have been in the range of 10 to 15%.

If ε is defined as the ratio of fuel energy saved by the solar system to solar energy delivered, then P_s/ε represents the levelized price of solar energy per unit of fuel energy saved. This can then be directly compared to the levelized price of fuel $P_{fo} \cdot \mathrm{LF}$, that is used in the conventional process heat system, where the levelizing factor is given by,

$$\mathrm{LF} = \frac{\mathrm{CRF(R,N)}}{\mathrm{CRF(R''',N)}} = \mathrm{CRF(R,N)}\,\frac{1+g'}{R-g'}\left[1 - \left(\frac{1+g'}{1+R}\right)^{N}\right]. \qquad (3)$$

* Footnote on next page.

TABLE 1. Nomenclature.

C_s	Levelized (annualized) required revenue in current dollars to purchase solar energy.
C_s'	Levelized required revenue in constant zero-year dollars to purchase solar energy.
CRF(R,N)	Capital recovery factor = $\frac{R}{1-(1+R)^{-N}}$ [See Appendix H for table of values.]
DEP	Present value of depreciation charges as a fraction of initial investment.
DP	Depreciation period (accounting life for tax purposes).
E_s	Annual solar energy provided by solar system at point-of-use.
ϵ	Solar effectiveness factor = fuel energy saved by solar system divided by solar energy delivered.
f	Fraction of total initial system investment financed by loan.
g	Assumed general inflation rate over life of system.
g′	Assumed overall escalation rate (includes general inflation) of conventional fuel used in backup system.
I	Total initial solar system investment in zero-year dollars.
LP	Loan period (always to be taken as equal to or less than system life).
M	The "M-factor" = C_s/I. Levelized required revenue per total investment dollar.
$m(t_c)$	Major component replacement cost in year $t = t_c$ as a fraction of total initial investment. This cost is to be expressed in terms of zero-year dollars.
N	System life. Also the period over which system costs are measured in a life cycle cost calculation.
OMPI	Levelized cost in current dollars for operation, maintenance, property tax, and insurance, as a fraction of total initial investment.
$OMPI_0$	Average cost of above items, expressed in zero-year dollars, as a fraction of total initial investment.
P_f	Levelized price of fuel ($/MBtu, $/kWh, $/GJ)
P_{f0}	Price of fuel in zero-year.
P_s	Levelized price of solar energy = C_s/E_s ($/MBtu, $/kWh, $/GJ).
R	After-tax, market rate of return on investment.
R′	After-tax, real rate of return on investment.
	$R' = \frac{1+R}{1+g} - 1$ $\qquad R'' = \frac{1+R}{1+r} - 1$ $\qquad R''' = \frac{1+R}{1+g'} - 1$
R*	Internal, after-tax, market rate of return on solar investment.
R_G	Compound, after-tax, market interest rate at which solar investment dollars grow, evaluated at the end of solar system life.
r	Market interest rate on loan.
r′	Real interest rate on loan.
S	Net salvage value of solar system, expressed in zero-year dollars, as a fraction of total initial investment.
SOYD	Sum-of-years digits method of accelerated depreciation.
t	Year of system operation under consideration. System constructed in year zero and begins operation on first day of year one.
t_c	Year in which a major component replacement is made.
TC	Total investment tax credit rate.
τ	Marginal composite income tax rate = $\tau_s + (1-\tau_s)\tau_f$.
τ_f	Marginal federal income tax rate.
τ_s	Marginal state income tax rate.

The market internal rate of return (IROR) on the solar investment is that rate of return for which the levelized cost of energy from the combined solar/conventional system is equal to the levelized cost of energy from the conventional system alone. The IROR is the annual after-tax, market, rate of return on the unamortized equity solar investment. To obtain the IROR, R = R*, one must solve the following equation, by trial and error or graphically,

$$\frac{M(R)}{\epsilon} \cdot \frac{I}{E_s} - P_{f0} \cdot LF(R) = 0. \tag{4}$$

---

*We prefer to use the term "levelized price" rather than "levelized, before-tax, cost" of solar energy in order to make clear that it can be directly compared to the levelized price of a competing fossil fuel.

THE EFFECT OF GOVERNMENT INCENTIVES ON ECONOMIC ATTRACTIVENESS

On the basis of present solar system costs, if there is to be a rapid expansion in the use of solar energy by industry, the government must either mandate its use or else provide a sufficiently attractive set of economic incentives to the potential user. The three common incentives that the government can provide the user are: accelerated depreciation (rapid write-off of investment), investment tax credit, and loans at below-market interest rates.

The 1978 National Energy Act allows a 20% investment tax credit for solar process heat systems. President Carter has recently proposed that this be increased to 25%. Legislation recently introduced in the Senate would provide a 50% tax credit. It hence appears that the tax credit mechanism will be the main government vehicle to push the use of solar energy by industry. It is therefore of interest to examine the effect of the tax credit, combined with accelerated depreciation, on the IROR to be expected for an all equity (zero loan) solar investment.

The ratio I/E_s is the basic cost/performance parameter appearing in Equations 2 and 4. Present systems are characterized by values of I in the range of \$30 to \$50 per square foot of aperture and values of E_s in the range of 0.2 to 0.3 MBtu/ft^2 year. Therefore, a reasonable value of I/E_s to represent present industrial solar systems is \$160/MBtu/yr. With improved collector and system design and a mass-production capability for producing collectors, this could possibly be reduced to \$60/MBtu/yr.*

In Figure 1 is shown the relation between the IROR (R*) and TC for three values of I/E_s, \$60, \$100, and \$160/MBtu/yr. Curves are shown for two values of fuel escalation rate, g' = 8% and 10%; i.e., 2% and 4% over the assumed general inflation rate g = 6%. Other parameters used to construct Figure 1 are:

Sum-of-years digits depreciation
DP = 7 yr
P_{fo} = \$4.10/MBtu (\$24/bbl)
ε = 1.4
$m(t_c) = 0$

N = 20 yr
$OMPI_o = 0.01$
S = 0
τ = 50%

---

*Large-area (> 1 acre) shallow solar pond systems, providing 130-140°F hot water, can be built for \$60/MBtu/yr or less. However, for conventional flat-plate water or air heaters and for line-concentrators, the \$160 cost is typical of systems being built today, with the better systems under ideal conditions perhaps as low as \$100/MBtu/yr.

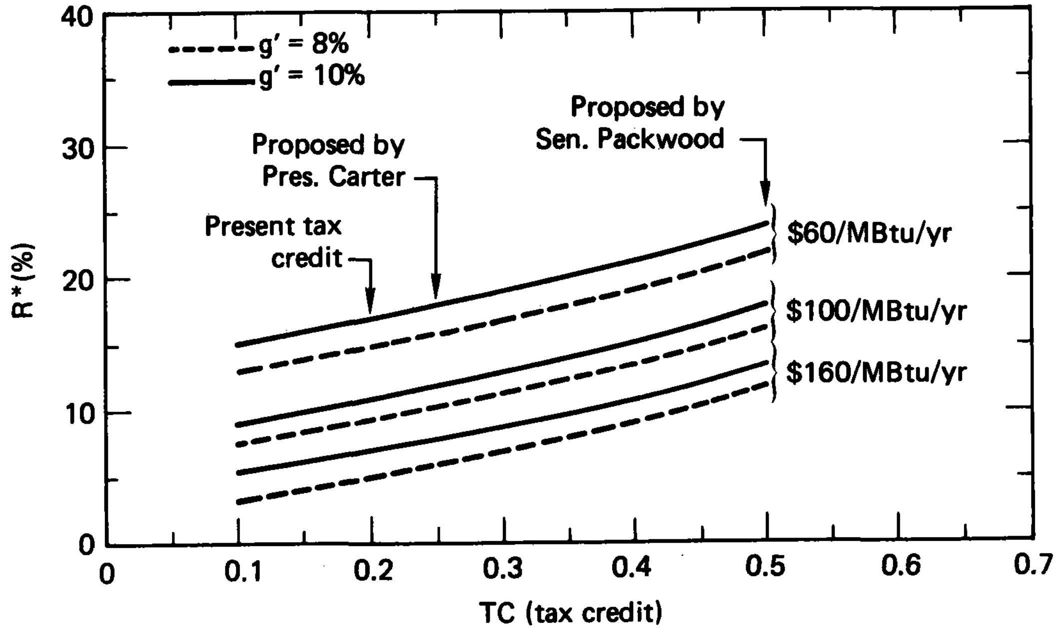

Fig. 1. Relation between market internal rate of return (R*) and investment tax credit (TC) for an all equity investment in a solar system. Other parameters listed above.

If industry requires a 15 to 20% IROR for a solar investment, a 20 to 30% tax credit would be needed for \$60/MBtu/yr systems and a 50% tax credit would be needed for \$100/MBtu/yr systems. However, it is seen from Figure 1 that, even with the 50% tax credit, \$160/MBtu/yr systems would require an additional incentive to reach the 15-20% IROR.

The question to be next addressed is: What combination of investment tax credit and loan would be required to make the present generation of \$160/MBtu/yr solar systems attractive to industry? Figure 2 shows the relationship between loan fraction (at a 9% interest rate) and investment tax credit that would provide values of IROR of 12%, 15%, and 20%.

It is seen from Figure 2 that to achieve a 15-20% IROR on typical industrial solar systems being built today would require a 50% tax credit, accelerated depreciation, and a 15 to 25% loan at 9% interest. If only a 25% tax credit is allowed then the loan fraction would need to be about 60%. [Of course if the loan interest rate were reduced, the required loan fraction would also decrease.]

As the reduced availability or the fear of shortages of fossil fuel becomes a more important concern of industrial process heat users, the rate of return requirements may be relaxed for energy-related investments. Such investments may be classed as "mandatory" or "survival" rather than "discretionary." From Figure 2 it is seen that the 50%

tax credit now under consideration by Congress would be sufficient to provide a 12% IROR without any additional incentive other than accelerated depreciation. If we can look forward to typical system costs soon coming down to the neighborhood of $100/MBtu/yr, Figure 1 shows that the 50% tax credit would provide the 15 to 20% IROR now desired by industry.

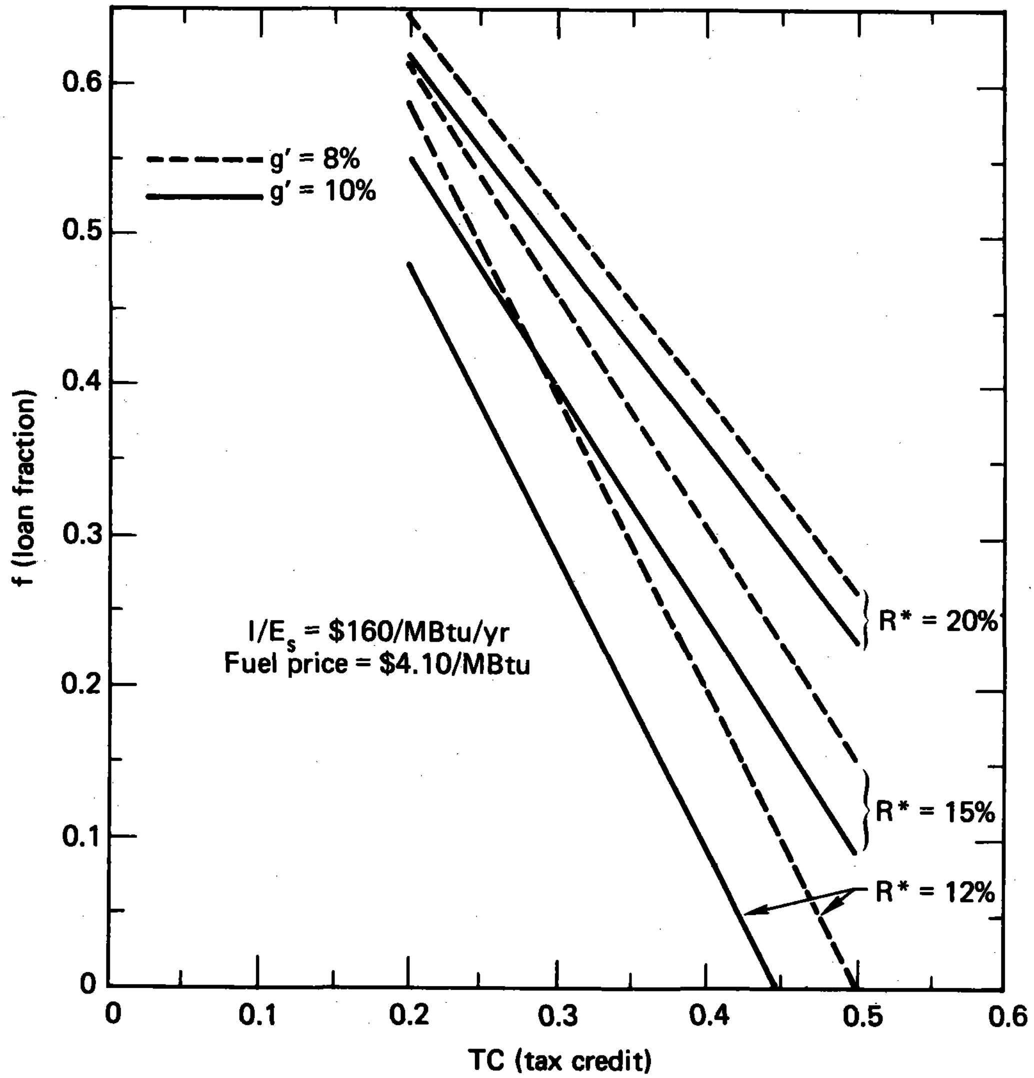

Fig. 2. The relation between loan fraction (at 9% interest) and investment tax credit necessary to achieve market internal rates of return of 12%, 15%, and 20%. Solar system cost = $160/MBtu/yr. Other parameters same as for Fig. 1.

GOALS: OBJECTS AND MEASURES OF PROGRESS

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ABSTRACT

One of the most useful outputs of systems and market analysis is a concise statement of technology goals. This short paper introduces the concept of goal-setting as previously developed in other programs of research and development. In this context "goals" are merely the visible output of a systematic translation of market requirements into research and development actions. Cost goals are one type of information linkage between market and research, although a complete statement of technology goals must include both tangible and intangible physical requirements as well. The process of devising goals and measuring progress against these goals is briefly illustrated in an example from the Solar Industrial Process Heat Program. The process of establishing a program framework and program goals has not been completed for solar process heat; it is hoped that this paper will encourage steps in this direction.

THE MEANING OF GOALS

It has been said that if you have no goal, then any path will get you there. Restated, this precept implies that a lack of goals leads to some degree of aimlessness; in fact, that the absence of a goal is the absence of any guarantee of progress. For most of us there has always been a clear and unreserved need for goals. What is unclear, however, is the precise meaning of the term "goal" in given situations, particularly with respect to technology development. Is a goal a single number, like \$/MBtu or mills/kWh, or is a goal a set of many related numbers? Is a goal quantitative like "ft^2 installed" or qualititative like "acceptance"? And finally, are goals set once and for all, or are they variable, destined to swing with the vagaries of the market or the realities of research? Goals for new technology, just as goals in management, politics, or human relations, are not effective unless these questions are answered and precise and useful definitions obtained. This paper attempts to define the meaning of research and development goals by describing their purpose, the framework in which they are determined and utilized, and the process of program development to which they contribute.

Webster defines a goal as "the end toward which effort is directed" hence, an "objective." The definition of a goal as an object of effort is undoubtedly the most familiar to us. However, Webster also indicates that goals are a form of scoring system, that is, "measures" of our progress toward some end. It will become clear in the following discussion that goals must be both objects and measures of progress. Effective goal-setting provides both ultimate and intermediate targets, and through the process of program review, goals provide a measurement of our success.

A PROGRAM FRAMEWORK

Federal support of solar energy research and development is predicated on the ability of solar technologies to contribute significantly to the energy supply of the United States. Therefore, solar research must be an applied research program with accountability to the energy needs of various users. This accountability does not require that the market always dictate technological advances nor that research always contribute directly to meeting or modifying those needs. Accountability does require, however, that the relationship of research and development (R&D) activity and market needs be recognized and that development programs have a structure such that information flows freely from market to research activities and such that the accomplishments of research activity impact current market needs. (See Fig. 1).

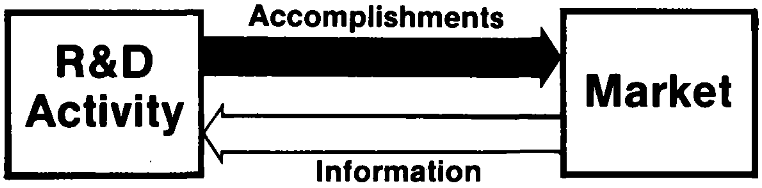


Figure 1. The Relationship of R&D Activity and Market Needs in an Applied Research Program

In the private sector the communication between market needs and research occurs with little conscious effort required to facilitate it. Private market forces of supply and demand are at play to allocate effort devoted to commercially viable technology. For developing technologies where government support is elected, however, this private market communication mechanism does not exist. By setting program goals, we are attempting to reproduce in an imperfect way a market structure for which no free market presently exists.

In Fig. 2, two basic functions of market/research communication are suggested. These functions are primarily related to cost since cost (or price) relationships are the traditional mechanism through which the market and R&D activities communicate. Beginning with an assessment of energy use, including the status of competing energy prices, required investment returns, risk and other application related factors, a "cost model" is constructed to interpret market needs and to yield a competitive price goal for the new technology. Given this price goal, the analyst must provide a "goal allocation", that is, the translation of a price goal into specific technological goals. Goal allocation consists of identifying required system performance and required system, subsystem, or even component costs. The level of detail to which this allocation is taken depends upon the detail required to direct R&D activities.

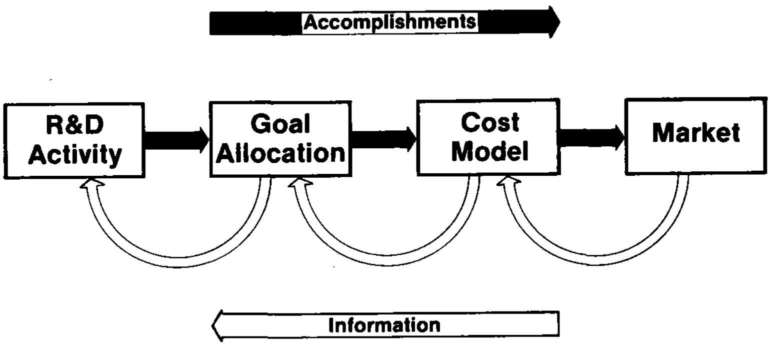


Figure 2. The Conventional Economic Linkage Between Market and R&D

In the same way that information is transferred from the market to R&D activity, progress in research and development can be compared against market needs by reconstructing a price from new performance and cost information. In this direction (see the "Accomplishments" arrow in Fig. 2) the analyst must model the performance of the new system, subsystem, or component and calculate new overall costs of energy. This cost is compared directly to the price goal earlier established or to new or modified market conditions through the cost model.

Actual free market communication is considerably more complicated than shown in Fig. 2. Figure 3 shows a more complete framework in which traditional economic factors link market and R&D activities across the top and where noneconomic factors are shown across the bottom. Note that a behavioral model and an economic model are shown separately. Information on decision behavior contributes to the construction of the economic model and also provides some noneconomic information (such as attitudes toward risk, public awareness, innovative spirit, etc.). In addition, the interpretation of the physical performance requirements of the user is shown contributing to the formulation of system simulation models (a part of "cost goal allocation") while also contributing to the transfer of information directly to research that is not directly associated with measurable cost or performance (such as simplicity or environmental acceptability).

Figure 3 is a complete representation of a goal-oriented program framework. Functions, data, or activities are shown in boxes, while information linkages, indicated by blank arrows, result from the goal-setting process. As an example of the process of program review within this framework, a typical problem in solar process heat applications will be examined.

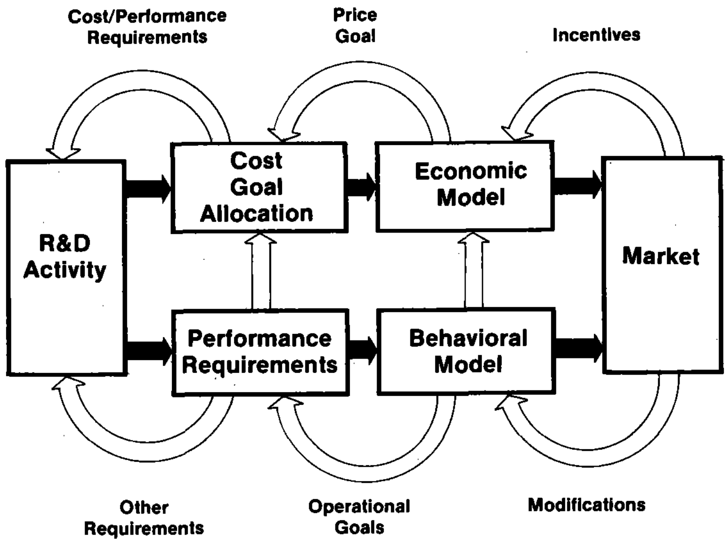


Figure 3. A Complete Goal-Oriented Program Framework

AN EXAMPLE OF GOAL ALOCATION

A great deal of work has been done in designing representative solar thermal systems for industrial process heat (IPH) and in projecting levelized costs and/or rates of return for such projects. Much less has been done in determining the contribution of manufacturing and installation to the costs of solar thermal IPH systems. Without an allocation of price goals among categories such as the cost and productivity of field labor, the cost and efficiency of solar collectors, costs of field piping and so on, R&D activity cannot be directly linked to market needs.

Cost goal allocation is basically a process of cost engineering analysis. For example, Fig. 4(a) illustrates the process of deriving the required cost of collector equipment (in $\$/\text{ft}^2$) from an initial price goal of \$6/MBtu, given a system average annual output of 0.30 $(\text{MBtu/yr})/\text{ft}^2$. Such an analysis indicates that collectors must cost $\$4.13/\text{ft}^2$ given the current status of field installation practice. More significantly, the analysis indicates that other more important areas for cost reduction may exist (such as a reduction in field labor-to-materials ratio). Using projections for improved field labor-to-materials ratio and indirect cost allowances, the analyst can also work backward through the cost goal allocation process to compare the current cost and efficiency of collectors ($\$19.00/\text{ft}^2$ and 0.30 $\text{MBtu/ft}^2\text{/yr}$) to the established IPH Program goal of \$6/MBtu [See Fig. 4(b)].

Attention only to simple cost and performance goals neglects important market needs that are not so easily quantified and yet are of critical importance to the acceptance of new technology. The analyst must interpret the general operational requirements of the user and obtain specific goals for components and subsystems. For example, interviews with plant engineers in several industries have indicated that energy supply systems will be required to meet acceptable safety standards, environmental standards, not interfer with plant processes, and be simple to operate and maintain. These general goals are easy for the user to state; the job of the analyst is to translate them into subsystem and component requirements that are concrete, e.g., restrictions on certain heat transfer fluids used, provisions for booster heating or buffer storage, and standards for solid-state controls. While translation in noneconomic areas is more difficult to accomplish, it is nonetheless crucial to the effective introduction of solar IPH systems into the industrial market.

PROGRAM REVIEW PROCESS

The proper definition of goals, the establishment of a program framework, and the creation of the models for goal-setting are only a part of effective R&D program review. Program review is a process with identifiable steps. Obviously, the process must begin with the gathering of data on the status of the market and on the state of the technology applicable to the market. These data support the development of appropriate models and also contribute to the formulation of various goals. R&D progress toward such goals should then be measured on a regular basis. In addition, due to changes in market needs and the advancement of competing technologies, these goals and models must be reviewed and revised regularly. In short, program review and management entails:

(1) The establishment of an appropriate comparative framework;

(2) the provision of timely data;

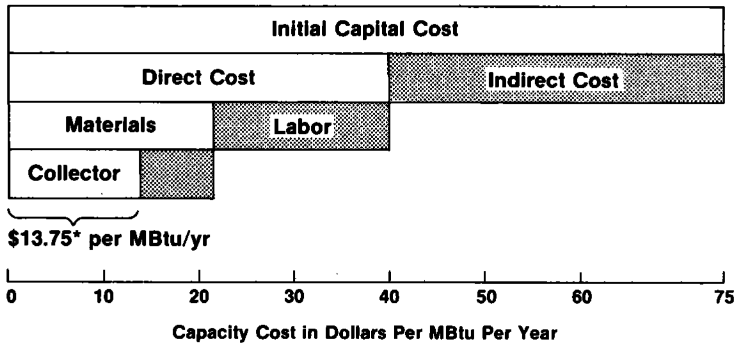
(3) the creation of required models;

(4) the fixing of goals; and

(5) regular review and revision of data, models, and goals.

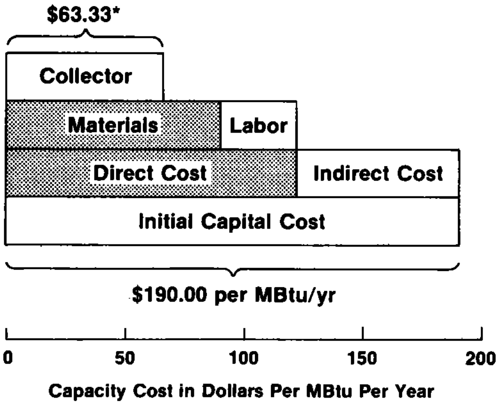
CONCLUSION

The principle of "management by objectives" has been widely advertised to almost every level of private and public administration. While the conventional meanings often attached to this principle may seem only distantly related to technological innnovation, it is still possible to apply "objective management" principles in the creation of goals that can be used to give emphasis and direction to a research and development program. To state that solar IPH can (or must) contribute 2.6 quads of energy by the year 2000 is not enough to guarantee success in meeting that goal. While "2.6 quads" is a goal, it is not a goal on which progress can be usefully measured or toward which research can be specifically directed. Long-term goals must be supported by more specific and short range objectives. Progress toward long-range targets must be measured regularly and new, more fruitful, directions identified quickly; this requires that a tactical framework for program review be adopted and followed. The goals we set, and more importantly, the roadmap which we select, are the only guarantees we have that "progress" will be more than just aimless wanderings along any path toward nowhere.



* For annual energy yield of 0.30 Btu/yr per square foot, the required collector cost is $4.13 per square foot.

Figure 4-a. Allocation of a Price Goal of $6.00/MBtu to Require Collector Costs in the Near Term. (An industrial fixed charge rate of 8% is assumed. The required initial capital cost is then $6.00 divided by 0.08 or $75.00 per (MBtu/yr) initial capacity cost.)



* For an annual energy yield of 0.30 MBtu/yr per square foot, and a collector equipment cost of $19.00/ft^2, the collector capacity cost is $63.33 per MBtu/yr.

Figure 4-b. Comparison of System Costs to a Goal Given Current Collector Costs and Projected Eventual Distribution Among Cost Categories. Using an 8% industrial fixed charge rate, the levelized cost of energy from the system is 0.08 × $19.00 or $15.20/MBtu. The cost per square foot installed is $190.00 × 0.30 = $ 57.00.

Working Groups

SOLAR INDUSTRIAL PROCESS HEAT CONFERENCE
Working Group Summary: Near-Term IPH Markets
November 2, 1979

Panel members: Peter Ketels, SERI, Chairman
Jim Rogan, McDonnell-Douglas
John Schaefer, Acurex

The panel members met prior to the working group sessions for the purpose of formulating session objectives. It was mutually agreed upon that a near-term market would be defined in terms of annual square feet of collection sales rather than numbers of installations or specific applications. A near-term market was defined as initial annual sales of 1.5 million square feet of collector area in the initial year with incremental increases in each year following. This level of sales would support 4-5 manufacturers of collector systems. It was further agreed that sales would have to commence, at the initial level, within the next 5 years to be considered as near-term.

For purposes of stimulating discussion among working group attendees each session was opened with the statement that, "There are no near-term markets." This statement was based on the following conditions:

- Absence of effective national energy plan/policy.
- Availability of conventional fuels, adequate.
- Conservation measures undertaken to date are incomplete.
- Reliability of solar systems is not proven.
- Land/space availability very low at existing plant sites.
- Interaction with industry insufficient to date.

It was expected by the panel and became evident at the start of each of the sessions that the attendees were expecting to be told by the panel what the near-term solar IPH applications were. In-turn, each of the above points were introduced by the panel followed by open discussion.

A national energy policy/plan is required for the purpose of providing limitations and guidance to industry in a single cohesive document. Such a policy would provide industry information required for planning in the immediate and near-term time frames. Existing legislation and policy is fragmented and subject to limitation in terms of providing industry guidance for planning.

At the present time, and in the immediate future, the availability of conventional fuels for industrial use is not expected to be curtailed and supplies are expected to be adequate. During 1974-75 many industrial energy users were approached by local utility companies and state public utility commissions to stop or curtail the use of natural gas as a primary fuel. Industry was encouraged to seek alternative energy sources. Currently, in direct contrast to the above situation, utilities in some regions of the country are actively encouraging increased utilization of natural gas. As a result of this change of events industry is confused and uncertain and has become reluctant to commit to alternative sources of energy unless thoroughly convinced of the necessity to do so. The status of the availability of conventional fuels is directly related to the implementation of an adequate energy program.

To date, conservation steps that have been implemented by industry have been those that are least costly and have resulted in some efficiency improvements in energy utilization. These measures have not resulted in the expenditure of large sums of money, purchase of more energy efficient production equipment, or alteration of production methods or scheduling. It was the consensus of the panel that more sophisticated conservation measures, (i.e., heat recovery systems) those involving major equipment purchases and longer term payback, are available to industry for implementation. Any consideration given to solar energy sources would have to compete with these more complex conservation measures in terms of economic evaluation.

With the exception of "innovators," industry is generally unwilling to adopt technologies or equipment that has not been proven to be reliable in terms of performance and operating life. To date, industrial solar energy systems have not sufficiently met the same criteria of reliability and performance that conventional equipment has. Traditionally, industry assumes relatively short equipment life for tax purposes, but real life can often exceed 20 years. It is reasonable to assume that the same expectations would be required of solar energy systems.

The availability of land and adequate space within existing plant sites is an important factor in the consideration of solar energy supply systems. The majority of existing industrial plants are located in densely populated urban areas thus placing a limitation on the availability of land suitable for locating a solar collector system. In the absence of the availability of additional land, consideration would be given to locating the collector system on the roof of the structure. Such consideration is subject to the same limitation as the availability of land adjacent to the site. Many older plants are not capable of supporting a roof mounted system without extensive modification. In such cases the cost of this modification can approach the cost of the solar system itself. In a retrofit situation, plants located in suburban areas offer the most promise because additional land is more apt to be available and the structure is more likely to be capable of supporting a solar system because they are newer with a uniform roof line.

The last condition influencing near-term markets is the degree of awareness among industrial energy users concerning the current state of the development of solar energy systems in terms of the potential for supply energy, primarily process heat, at the conditions required. Most industrial energy users think of solar energy in terms of flat plate collectors and are not aware of the potential of concentrating collectors, point focus dishes, and central receivers. If solar energy is to penetrate the industrial market segment and displace fossil fuels an intensive awareness program must be undertaken, and if necessary taken directly to the industrial energy user. Aside from economics, solar energy is regarded as pie-in-the-sky, an exotic form of energy.

The combined attendance at the two working group sessions was approximately 65 people. Of this total approximately 6 attendees represented potential industrial users of solar energy, 15 solar energy equipment suppliers, designers, manufacturers, and the remainder were comprised mainly of government research contractors or representatives of Federal and state government. The question was posed to the manufacturers of solar equipment, "How many of them actually had solar energy systems installed somewhere on their own facilities actually supplying some energy to their process needs?" Of the manufacturers present only two indicated the use of energy derived from a solar source. One other equipment manufacturer indicated the installation of a solar system at some time in the future.

The following statements summarize the major points discussed during the open working group sessions:

- More extensive conservation measures will be undertaken when a national energy policy materializes.
- Conservation measures and solar energy systems will be considered together, presently conservation is more attractive financially.
- Plant engineers and managers look to "years payback" as the initial screening criteria during the investment decision process.
- Federal and state tax incentives are needed in the near-term.
- The government should issue less restrictive RFP's and PON's relative to applications and the types of solar systems to be employed therein.
- Industry is generally unfamiliar with solar energy - there is a great deal of concern regarding its complexity and the need for additional manpower in connection with its operation.

A consensus of opinion was reached among the working group attendees, taking all of the above factors into consideration, as to specific types of conditions/situations that would lead to and constitute near-term solar industrial process heat markets. These conditions can be summarized as follows:

- Industries faced with increasingly unfavorable conventional energy economics.
- Industries threatened with the inability to secure increased quantities of conventional energy supplies to support growth, threatened by curtailment, or dependent upon continuity of supply to meet processing needs.
- Industries accustomed to self sufficiency in terms of energy supply, i.e., cogeneration, or accustomed to the operation of moderately sophisticated technological equipment, i.e., dairy plants.
- Industries subjected to legislative or regulatory constraints such as a limitation on emission levels which would prohibit increased consumption of conventional fuels, i.e., the state of California.
- Industries which place heavy emphasis on public relations image and exposure.
- Construction of new plants in which solar energy would be easier to implement and finance.
- Continuation of government supported demonstration programs at a level to adequately support solar equipment manufacturing operations, and also help to develop the factor of reliability required for wider acceptance of solar energy systems.
- Unique siting situations where a large amount of energy is consumed in the transport of energy from one point to another, i.e., remote mining operations.

COST GOALS & INCENTIVES WORKING GROUP

Panel Members
Ab Davis, JPL (Chairman)
Loren Hov, Stauffer Chemical
Gus Hutchinson, Solar Kinetics
Jim Doane, SERI

I. Introduction

A total of approximately 80 people attended the two sessions of the cost goals and incentives working group. In each session discussion was focused into three topical areas: The goals that the technology must meet for solar energy to be relevant to the using industry; the goals that can be achieved by solar energy system vendors; and the role of government in providing incentives to the market. The range of opinions expressed is summarized here.

II. Relevant Goals (Loren Hov, Discussion Leader)

Economic goals - For industry to be interested in solar energy the cost and performance of the systems must make solar energy economically attractive -- economically attractive on industry's terms. Solar energy will be compared with the cheapest available fuel that environmental regulations and fuel allocation rules will allow.

Three methods will be used by industry to evaluate solar IPH projects: Discounted cash flow, internal rate of return, and after-tax payback. The economic methodology prepared by W. C. Dickinson and K. Brown was widely accepted by the user industry present at the workshops. However, there was general disagreement with some of the parameters selected for the example cases. Industry practice in evaluating prospective investments deliberately reflects some degree of conservatism. Values for conducting economic analyses meeting with approval from industrial users included:

- Setting expected return on equity to 5 to 10% above the return on equity achieved by the company in the recent past. But each company has its own standards. Required ROI's of 25%, 28%, and 40% were mentioned by users.

- Using 100% equity financing for preliminary screening. (Debt financing would only be considered if a special government program was available for project-specific financing.)

- Long actual life of equipment is viewed with skepticism. The practice in industry is to set actual life = tax life. In this case the equipment appears to be in the same category as "production equipment." Therefore the analysis should assume a 10 to 12 year life.

- It is common practice to assume that the salvage value is zero in the analysis of prospective investments.

Operational goals - Economic attractiveness is a necessary condition for industrial use of solar technology, but it is not a sufficient condition. The technology must also achieve certain operational goals in the areas of: (1) environmental acceptability, (2) reliability, (3) serviceability, (4) simplicity, (5) safety, and (6) warranty. Many of these operational factors have a direct impact on economics. Therefore, industry will place demands on the certainty with which these factors are understood before committing to use solar energy.

It was observed that the relevant goals do vary with system and specific site. In certain circumstances solar energy may offer advantages which offset its current high cost. However, these special circumstances are hard to find.

Chairman's comment: It was clear from the discussion at this workshop that it would be both useful and possible to initiate an activity to formalize the process of setting goals relevant to potential industrial users of solar energy equipment. This workshop and the establishment of a common framework for doing economic analysis are just the initial steps in the process. The cooperation of representatives from the user industry is essential to the success of this effort. Those in attendance were willing to help.

III. Achievable Goals (Gus Hutchinson, Discussion Leader)

There was essential agreement on two points. First, current collector technology has demonstrated performance approaching the point of diminishing returns on R&D investments. Second, field testing of systems continues to be important. While some R&D support in the area of performance quality is required to prevent sales of unsatisfactory equipment, greater gains are to be made in the area of reducing production costs. However, the main thrust of the DOE program should be in the area of market development. Collector costs will automatically be lowered through competition for a viable market.

One potential area where DOE action could increase the market size for solar energy involves current industry plant expansion requests. For expansion in areas of energy shortages or high pollution, solar could be required by DOE. Replacement of polluting fuels by solar could be required in the interest of an improved environment.

A wide range of opinions were offered on the potential cost for collector installations. They ranged from $10.00 to $50.00 per sq. ft. of aperture area. This represents an equipment price of $33 to $165 per million BTU's/year of energy delivered. One collector manufacturer estimated that the lowest cost could be achieved for installations in the 200 acre class, a second collector manufacturer estimated a cost of $66 and one employee of a large A&E firm suggested that no cost advantage would be realized with large projects other than the collector cost and insisted that $165/MMBTU/YR would be the lowest achievable even if the collector were supplied free of charge. The A&E's cited the normal cost of installing pipe and the realities of industrial construction with union labor to back up their position. Reflecting on this severe split in opinion, one experienced solar energy system vendor offered the comment that "organization may be the answer" to the installed cost problem.

The goal of collector cost reduction can only be achieved through an orderly and continuous growth in collector production. The ultimate mass production cost can only be achieved when the market exists.

It was noted that storage is not desirable for use in solar industrial process heat projects. It was suggested by some that funding currently earmarked for storage technology should be channeled to other more productive areas.

Chairman's comment: There is a very large difference of opinion within the supply industry concerning the cost performance goals which can be achieved by installed solar energy systems. There is a need to establish separate cost/performance goals for: the f.o.b. cost of solar collection equipment, the cost of installing the solar equipment in the field; and the balance of components making up systems. Management's standards for demonstrating progress of "achievable goals" toward "relevant goals" are needed by the program. These "management standards" need to be developed by consensus of the IPH R&D community, the solar equipment vendors and the A&E community.

IV. Incentives to the Market (Jim Doane, Discussion Leader)

Incentives are justified if required to normalize the market. That is to say, it is poor energy policy to profess a goal of decreased reliance on non-renewable fuels, yet cause such fuels to appear artificially expensive relative to their conventional competitors.

Incentives may also be justified to compensate for differences in externalities. If substituting solar energy for conventional energy produces social benefits beyond those captured by private users, then it is appropriate for government action to adjust private costs or private benefits to reflect those "externalities." That is, if environmental improvement increased national security, or more autonomous foreign policy are likely to result from adoption of solar technologies, public encouragement of such adoption in the form of subsidies is an appropriate policy. Consideration should be given to national security, environmental, and balance of trade factors.

Mandatory or quasi mandatory approaches met with resistance by potential industrial users. But non-industry people were in favor of giving regulatory support to the use of solar energy.

Preferred modes for implementing subsidies were discussed. Subsidies to users and subsidies to vendors were discussed separately.

Users would be responsive to tax credits. Two strategic approaches were discussed: The "empirical" approach, and the "adequate and stable" approach. In the "empirical" approach a tax credit is arbitrarily set. If industry responds, you leave it there. If industry fails to respond, you up the credit in rounds until the desired (by government) response is achieved. The "Adequate and Stable" approach requires government to be "smarter" in choosing the initial level of the credit but was the preferred approach.

Users would also be responsive to special financing arrangements. Low interest loans and subsidized third party ownership arrangements were mentioned. A representative of the California PUC noted that they are now examining the role of utilities as third party owners of solar equipment.

Vendors would like DOE to advance the funds needed to pay for front end tooling and production equipment. The vendor making this suggestion would be willing to repay the advance from DOE out of commercial sales from the production line. Such a program could immediately reduce collector costs by 25%. Vendors expressed a need for government help in finding buyers for large systems.

Chairman's comment: The subject of incentives is very difficult to deal with in an ad hoc discussion environment. Several of the participants felt the need for expert and considered input.

The general topic of appropriate level of incentives to users needs to be decided in a larger context of national energy policy. DOE's IPH program does need to consider how to best provide interim support to the equipment vendors for the transition from custom fabrication to industrial manufacture of solar equipment.

WORKING GROUP PANEL

SYSTEM CONFIGURATION AND PLANT INTERFACE ISSUES

Panel Members:
Jim Castle - SERI
Don Whetzle - Johnson & Johnson
Charles Roos - Jacobs-Del Solar Systems

Two, one-hour round table discussions were held on this subject with approximately thirty people in attendance at each. The objectives of these discussions were to establish state-of-the-art conditions, identify current problems and barriers and to recommend action. The subject area is very broad and, by necessity, only limited discussions were possible. Each session began with a listing of suggested topics for the discussion to follow. The panel served to guide the discussions with Don Whetzle providing a solar users point of view and Charles Roos speaking as a solar system designer. The individuals participating in the discussion covered a broad spectrum and represented, in aggregate, a great deal of solar knowledge and experience. The potential discussion topics which served as a starting point at the two sessions are shown in Table I.

Table I
POTENTIAL DISCUSSION ISSUES

A. System Configuration
  - Pros/cons of various configurations
  - Control features
  - Cold weather operations
  - Safety
  - Buffer storage usefulness
  - Modularity
  - Relevance of standards and codes
  - Component quality requirements
  - Maintenance needs
  - Automatic operation
  - Design check-list
  - Start-up/shut-down/emergencies
  - Confidence in performance claims

B. Plant Interface
  - Need for operator training
  - User involvemement in design phrase
  - Displays required for proper operation
  - Union conflicts
  - Process disruption
  - Check-out procedures/verifying performance
  - Availability of parts/service
  - Ground mount/roof mount trade-off
  - Contaminating environment

Several comments were voiced regarding the state-of-the-art with respect to the specific topics. The workshop notes show that those comments enumerated in Table II were generally accepted by the group.

Table II.
STATE-OF-THE-ART

1. Some solar system designers/installers will guarantee system performance. Collectors will be added if the thermal output fails to meet expectations.

2. One collector manufacturer believes that an annual production of at least ten million square feet is required before mass production techniques will be fully utilized.

3. The relative merits of stream production via flash blowdown and via an unfired boiler are uncertain.

4. A general shortage of solar engineers exists.

5. Lessons learned in the SHAC program are not being carried over to IPH projects effectively. This has resulted in a repetition of design and operational errors.

6. The IPH system user may be able to make cost-effective contributions to the construction process.

7. Large projects ($>10^5$ ft^2) provide few technical lessons beyond those gained in smaller projects. Large projects permit some additional optimization opportunities and may be more impressive to potential users.

8. Field tests have favored the sun-belt. Attention should be given to the northeast where the solar imput is less, but competing fuel prices are the highest. Unique problems may be uncovered in these northeast field tests.

9. Non-solar components have worked satisfactorily in existing projects.

10. Presently the collector manufacturer most often serves as the general contractor in order to sell his product.

11. New industrial energy plants are being designed to handle a variety of fuels in order to minimize disruption by specific fuel limitations.

Presently, a number of factors are acting to inhibit the application of solar energy systems within industry which are exclusive of financial considerations. The workshop attendees expressed in their discussions those items listed in Table III.

Table III.
CURRENT PROBLEMS AND BARRIERS

1. Conservative design habits represent a special burden to an already expenive solar system.

2. Users must be willing to modify their energy use patterns to maximize the solar system usefulness.

3. Insufficient attention has been given to training system operators.

4. The slow generation of reports during field test cycles has resulted in repetitious errors.

5. Some potential users are holding back waiting for the creation of a federal "energy bank" which will provide attractive funding opportunities.

6. Existing regulations encourage conventional fuel usage.

7. Data acquisition systems have not provided a thorough record of system performance. This results in poorly substantiated system performance claims.

8. The plant environment to which the solar collectors will be exposed is often not well characterized.

9. Technical details regarding solar collectors (installation and operation) have not been effectively conveyed to A/E firms.

10. Contractors are unacustomed to working with heat transfer oil systems (which require careful assembly).

As a consequence of the workshops' assessment of the state-of-the-art and current problems and barriers a number of actions were recommended. The items found in Table IV serve to summarize the workshop activity with respect to configuration and interface issues.

Table IV.
RECOMMENDED ACTION

1. Strong efforts must be made now in order to meet year 2000 goals for energy contribution by solar.

2. Greater advance notice of Program Opportunity Notices (PON's) would enable more firms to respond.

3. Economic incentives must be available to all industrial energy users.

4. Research is required in the direct generation of steam in the collectors.

5. Users must verify this necessity of steam and/or energy delivery temperature prior to system design.

6. Multiple small projects encourage the development of a larger engineering talent reservoir.

7. Projects should be funded so that the user can hire its own solar engineer to follow the technical evolution of the system (possibly on a part time basis).

8. Solar generation of conventional-type fuels should be encouraged.

9. Design solar systems in modular packages so that users can readily install themselves.

WORKING GROUP REPORT: HARDWARE DEVELOPMENT NEEDS

J. Banas, Sandia
J. Buggy, Westinghouse
M. Delgado, Del Manufacturing
H. Gerwin, Sandia
A. Schwartz, Consultant
J. Williams, Honeywell

Two distinct topics were addressed in the Working Group on Hardware Development Needs: hardware development needs and programmatic guidance. Hardware development needs were discussed for approximately one-quarter of the allotted time whereas comments, which for the purpose of this report can be categorized as programmatic guidance, were discussed for approximately three-quarters of the time. For both topics only a small number of participants provided comments.

Development is needed in the following areas: structures, reflective materials, receivers, selective coatings, trackers, drives, flexible hoses, field layouts, test equipment, and cleaning equipment. There was a general consensus that no one particular area was the key problem area, that is, all areas need substantial attention.

Programmatic guidance to DOE can be summarized by the following remarks:

- Establish a stable program.
- Provide faster response in proposal reviews and contracting.
- Establish test facilities (environmental as well as thermal) for product improvement testing to be accomplished outside of public eye prior to qualification testing.
- Procure iteratively multiple, small (10,000 square feet) systems to accomplish product improvement; provide follow through funding for performance evaluation by component and system designers; <u>require</u> hardware development prior to system fabrication.
- Site these experimental systems at government-type facilities to promote current developmental nature of technology.

SUMMARY OF WORKING GROUPS ON HIGH TEMPERATURE IPH APPLICATIONS

PANEL MEMBERS: J. Fish, H. Webb, J. Graf

Attendees included solar equipment manufacturers, national laboratory personnel, and one potential solar user.

A wide range of topics were discussed. Only those statements on which there was fairly general agreement are summarized below.

- The IPH market is not well characterized.

- Potential users are not well acquainted with the technology options.

Early user and solar manufacturer involvement in DOE programs was proposed as a partial solution to the two problem areas above. Incentives to make solar more attractive economically would accelerate user involvement. Representatives of manufacturers suggested that DOE specification of design should be minimized as much as possible.

- Better instrumentation of future projects would speed user acceptance.

Due to a lack of standardization of data gathering equipment and a failure, in some cases, to maintain properly the equipment that has been installed, many of the DOE demonstration projects are not well documented. The projects, therefore, have not been as useful as they could have been.

- Complete development of technology aimed at lower temperature applications first.

A number of attendees felt that the lower end (500-1000°F) of the high temperature range of IPH applications was the most viable near-term market and that solar technologies to supply this market were in an advanced stage of development. There was some discussion with respect to whether higher temperature technology should be developed before adequate demonstration of the lower temperature options.

Industry User Panel

USERS PANEL

Moderator: Rosalyn H. Barbieri
Jet Propulsion Laboratory

Panelists:

Eric Burnett
ARATEX Services, Inc.
Industrial Laundry
Fresno, California

Loren Hov
Director of Energy Management
Corporate Director of Energy Activities
Stauffer Chemical Co.
Westport, Connecticut

Orin Murray
Industrial Solar Associates
Florrisant, Missouri 63033

Charles R. Strong
Johnson & Johnson Products, Inc.
Serman, Texas

James B. Trice
General Electric
Philadelphia, Pennsylvania

Harold Wilkening
AAI Corporation
Baltimore, MD

SUMMARY

A panel of six industry representatives participated in a discussion on the use of solar energy in industry. Three were users and three were designers of solar IPH systems. Orin Murray was the only representative of a privately funded IPH installation.

A series of questions were sent to the speakers prior to the conference in order to focus their discussions on issues considered to be pertinent to IPH. A copy of these questions is attached at the end of this summary.

The purpose of the Users Panel was to obtain information from representatives of private industry on their experiences with solar energy and their perspectives on the future for solar energy in industry, the processes by which private industry makes decisions, possible improvements industry/government interaction, and means for improved dissemination of results of solar IPH activities to the industrial sector.

Once each member of the panel had spoken, the floor was opened to additional questions. One particularly valuable comment from the last round of discussion was the response by all the panelists to a question asking whether the economic methodology developed by Bill Dickinson and Ken Brown was appropriate and useful. The panelists agreed unanimously that it was well thought out, accurately represented the type of analysis generally used in the industrial market, and should be a very useful tool for industry in evaluating the benefits of solar IPH systems.

Orin Murray, Industrial Solar Associates

Orin Murray began the discussion with his comments on the Anhauser-Busch (A-B) hot water installation in Jacksonville, Florida. A-B is typical of most industrial installations, privately or federally funded. The decision to install a solar energy system was made by the president of the company as an R&D experiment. Energy prices are rising, and the solar system afforded the opportunity to learn more about solar energy and to make mistakes before interruptions to conventional energy occurred.

The more traditional and conservative of the senior corporate management were reluctant to go along with this "gadget" and did so only because the president had made the decision. (Later conversations with Murray revealed that plant management in Jacksonville, however, was delighted with the system and took a proprietary and protective approach.) The system, although producing only a 1% ROI according to the St. Louis office of A-B, was making a positive contribution financially. At current costs, however, A-B would not expand the existing system or try another one.

Public relations was not one of the explicit reasons for installing the system. However, A-B has capitalized effectively on the publicity gained from the solar installation.

In response to the question concerning what DOE could do to make the job of selling or purchasing a solar IPH system easier, Murray stated that better and more available information would help considerably.

Harold Wilkening, AAI

Harold Wilkening is the Manager of the Energy Systems Department and designer and fabricator of the solar IPH system for the York Building Products Company. He spoke on behalf of Bob Stewart, Jr., VP of York and the motivating force behind the York decision to adopt solar energy.

The York Building Co. is the only DOE project with a newly constructed building in which the solar IPH system could be integrated in the initial building design. As such, it is the least expensive and the best integrated with the building and the process.

York Building is a privately owned firm with four plants that wanted to build a new facility. Bob Stewart had seen an AAI solar heating and cooling installation in the local area. He contacted AAI and said he was interested in a solar hot water system for his new facility. A proposal was submitted to DOE and accepted, and the system was installed. Although there have been a number of start-up problems, the system has performed reasonably well.

Bob Stewart is happy with the system, but he is not willing at the present time to install a larger system. This is largely due to the expense of the investment. Also, the structural support for the collectors added $4/ft more to the building costs, and there are too many rainy days when the collectors are in a stored position. Wilkening made the point that if this installation were in the sunbelt, significantly more Btus would be delivered to the load.

As contractor and manager for the York Building Co. project, Wilkening said that the freedom that DOE gave them in the design was highly beneficial to the ultimate system configuration. AAI was able to modify the design to best fit the specific situation at York. This flexibility should be maintained, providing adequate controls are established to ensure proper design of the system.

During the question and answer period, a number of key points were made. First, although 135°F water is now being provided to the load, flat plates were not used because initially experiments were being made at the plant with different temperature ranges (up to 190°F) to determine the optimal time/temperature trade-off for curing concrete blocks. Flat plates would not have allowed this type of experimentation to proceed and would have limited the capability of the system to respond to company thermal requirements.

Secondly, as part of their contractual effort, AAI trained the York people to maintain the system. Thus, the plant manager, who is responsible for all other equipment maintenance, is also responsible for maintenance of the solar system. This is a good approach to technology transfer, education, and training and should be part of any DOE engineering or field test experiment.

Loren Hov, Stauffer Chemical

Loren Hov, the most senior industry executive on the panel, offered good insights and comments on the financial implications of solar energy for industry and his perceptions of how and where solar IPH might succeed. Stauffer Chemical is involved in two DOE-funded projects or proposals, and has one solar domestic water heating system installed with internal dollars. The latter system was constructed primarily for the education of the workers and great pride is taken in this system.

The chief criterion in any decision to adopt a solar energy system is cost, according to Hov. Because of the current and expected costs of energy alternatives, Stauffer will use natural gas whenever possible or available. Otherwise, the company will use oil, then coal, and, finally, renewable fuel sources when they become cost-effective. This holds true especially for the top 10 energy-intensive industries, where energy costs and supplies are significant.

The ROI is a significant factor in capital investment decision-making. If the DOE solar program is looking for target industries as potential IPH users, Hov commented, it should concentrate on industries that have small ROIs in addition to the proper applications for solar energy. This is even true for cost-sharing projects since industries will cost-share only if their equity investment meets their internal ROI requirements. The federal funding requirement will be greater for companies with high ROIs than for those with smaller ROIs. Hov stated that published accounts of ROIs (such as can be found in the Jan. 8, 1979, issue of Forbes) are sufficient to begin to pinpoint those industries who, from a financial viewpoint, may be early targets for solar IPH systems.

Another factor that should be considered is that projects must be feasible to construct. In addition, the construction must not inhibit the production process in any way.

During the discussion period many questions were asked about the ROI and industrial investment decision-making:

- Regarding the question of whether third-party ownership of a solar system would enhance its economic viability, Hov doubted that this would be an effective mechanism unless costs decreased substantially. A third-party owner or entrepreneur would still have to make his profit, which thus adds to the cost of the system.
- Companies will generally try for higher ROIs than the minimum required because projections always seem to be higher than reality.
- Non-production-oriented investments are not valued as highly as production investments and, therefore, often require a 3-5% higher ROI. (Some industries are willing, however, to take a lower ROI for energy because of the uncertainty of energy costs in the future.)
- When asked about projecting fuel costs in making an investment decision, Hov said that two aspects of costs are considered in the decision: one is the cost of fuel and its projected price, and the second is the payback. Given the volatile nature of energy prices, it is easier to project over short periods of time. Therefore, the shorter the payback the better.

James Trice, GE

GE is involved in three solar projects. Trice spoke on the behalf of the owners, and also expressed his own viewpoint as a designer and manufacturer of a solar IPH system.

In all three projects, the decision to adopt the solar IPH system was made at the level of fiscal responsibility in the company. In the discussion that followed, it was generally agreed that the final decision was usually made at this level. However, necessary and positive input probably would have to come from the plant manager or chief engineer supporting the particular solar IPH design and hardware.

Two major criteria for participation in all three cases were the public relations benefits that could be derived from such an activity and the potential threat of curtailment of conventional fuels. Although conventional alternatives were available, the option of solar energy was sufficiently interesting to justify a DOE-funded or cofunded project.

The three firms reacted in different degrees to the idea of a government-funded project. For one company, it was just a matter of getting the DOE support. For another, there was some concern over participation because the costs were still substantially higher than alternatives. The third finally dropped out of the DOE project because (1) the ROI was not sufficient, especially given the size of the project, and (2) they were uneasy over the personnel requirements that a solar energy installation might bring; this is not an atypical response and is one of which the designer should be aware during initial discussions.

Another concern of industry, which has sporadically appeared in other survey efforts, is that participation in government-funded projects may cause the "feds" to come "lurking around the premises." Many industries feel uncomfortable in this situation and would rather wait until such a project can be internally funded in its entirety.

Lack of knowledge of solar IPH and lack of performance data were problems encountered in all industrial contacts.

Trice's comments on communication supported conclusions from previous solar industrial surveys; namely, that if the appropriate information is available, the existing channels of communication are adequate to disseminate the information. Plant managers and engineers know what they need and if there is an advantage to a particular system, piece of equipment, or process, they will find out about it. Word of mouth, trade associations, and professional organizations should be used to help disseminate the information industry needs.

Due to the newness and cost of solar IPH systems, greater user participation and subsidies are required to enable experiments to meet the investment criteria and interests of industry.

Several good issues were raised during the discussion period:

- The process by which GE found their industrial partners was very laborious—"agonizing," in their words. Initially relying on the two DOE national surveys (ITC; Battelle and Clemson), GE narrowed the field to food and textile industries (compatible with their evacuated-tube technology). They then surveyed representatives in the two industries before they finally found their corporate partners.
- In response to the question of whether GE was successful in selling solar products to other parts of GE, Trice said that GE considered it as they would any other type of investment. (In a later discussion, Exxon responded the same way about internal selling of Exxon solar products.)
- Public relations (PR) are an important consideration to some industries and may be included in economic considerations. For industries such as Stauffer Chemical, PR has less importance. In most instances, the more market-oriented and visible the product is, e.g., french fried potatoes or milk processing, the more likely it is that the PR value of solar use will increase.

Eric Burnett, Red Star Industrial Laundry, ARATEX Services, Inc.

Since this installation is one of the oldest experiments, Burnett's comments were very valuable. It was at his impetus and with his backing that ARATEX decided to participate in the project. It was an excellent example of an internal champion forcing something to happen. Although the installation initially was calculated to have a 60-70 year payback, ARATEX's contribution met the ROI requirement of the firm. Because of the uncertainty over future energy supplies, however, ARATEX did extend the allowable payback to 8-10 years for this particular investment.

The savings have been around $4000/year, which is less than originally anticipated. The returns on their heat recovery equipment purchases have been considerably greater. Technical problems with the original system design, collector surfaces, and selective coating have greatly reduced the system efficiency. Such problems might have been avoided if the system and design had been more thoroughly tested before installation.

At the plant there is little interest in the system, and the problems have exacerbated this situation. Once again, this apparently was a situation where central management decision imposed a system on a less than willing local plant. Even an internal advocate does not appear to be sufficient to create a positive attitude at the test site itself—an element critical to word-of-mouth communications and the resultant perceptions of solar uses.

The cost of the project originally was $233,000, with ARATEX supplying $55,000. The solar system has saved $4000/year while the heat recovery equipment is saving $12,000/year on a $30,000 investment. This again emphasizes that conservation must be undertaken before solar systems are installed. In general, solar energy cannot compete against the marginal cost of conservation. Burnett also felt that little could be done to reduce the cost of the system. Increased efficiency might improve the economics but the costs of hardware design and installation would not vary much.

Charles Strong, Johnson & Johnson

Johnson & Johnson has been somewhat unique in its approach to solar energy. An internal decision was made to look at solar technology and to become involved, if possible, in a DOE project. Consequently, they called DOE to determine who was designing and fabricating solar collectors. Johnson & Johnson then interviewed the manufacturers and made their selection accordingly.

Johnson & Johnson actively participated in determining the criteria, parameters, and design for the solar installation. They were able to make substantial changes in the design, which they feel improved the system. Originally, the solar system was designed to interface with a particular production process. During the design review it was determined that the solar system would be far more efficient if it provided steam to the central steam facility rather than to one particular process. The solar system is thus better utilized since it is not subject to the downtime of the particular process.

Aesthetics of the solar IPH installation were a large concern of Johnson & Johnson. Since the collectors would be located near the headquarters building, the site had to be made as aesthetically pleasing as possible. Shrubbery was planted to hide the collectors although some was subsequently removed when the collector field appearance proved to be more acceptable than originally perceived.

Charlie Strong was adamant about his feeling that the local plant in which the system is to be installed must be involved intimately with the design, installation, and maintenance of the solar IPH system. It is only in this way that plant management learns about the operation and characteristics of a solar system and takes pride in its successful utilization. Industry is uneducated about solar technology and good cost and performance data are required.

Strong is a solar advocate and would like to see solar applications in industry. For example, he gathered a group of approximately 25 people from other industries in the Sherman, Texas, area in order to introduce them to solar IPH potential and the prospects for its use. Because of his contacts and credibility, he was able to gather an influential and interested industrial group.

QUESTIONS

Question to Eric Burnett:

Would cost of project still be $233,00 today?

Answer:

All ARATEX proposal prep was donated no charge. Cost would be no more than 10% less if it was done today as a conventional project.

Question to Loren Hov:

Do you plan to file for exemption from incremental pricing of natural gas on the basis of economic hardship?

Answer:

No.

Question to James Trice:

How many millions of square feet per year would GE have to manufacture per year to use mass production techniques?

Answer:

200,000 sq ft/yr now (really already in a position to mass produce)

Question to Harold Wilkening:

How many millions of square feet per year would AAI have to manufacture per year to use mass production techniques?

Answer:

Exact figure unknown. Roughly 1 million per year.

SOLAR ENERGY APPLIED TO AGRICULTURE AND INDUSTRY

Jimmie F. Dollard, Chief
Agricultural and Industrial Systems Branch
Department of Energy

The following visual aids pertain to the closing remarks made by Jimmie Dollard at the conference.

STATUS OF NATIONAL IPH PROGRAM

WHERE ARE WE?

WHERE ARE WE GOING?

Basic Program Objectives

1. System Development

- Assist in developing and testing reliable, long life cost effective solar systems

2. Demonstrations

- Demonstrate prototype solar systems for a variety of industrial applications

3. Incentives

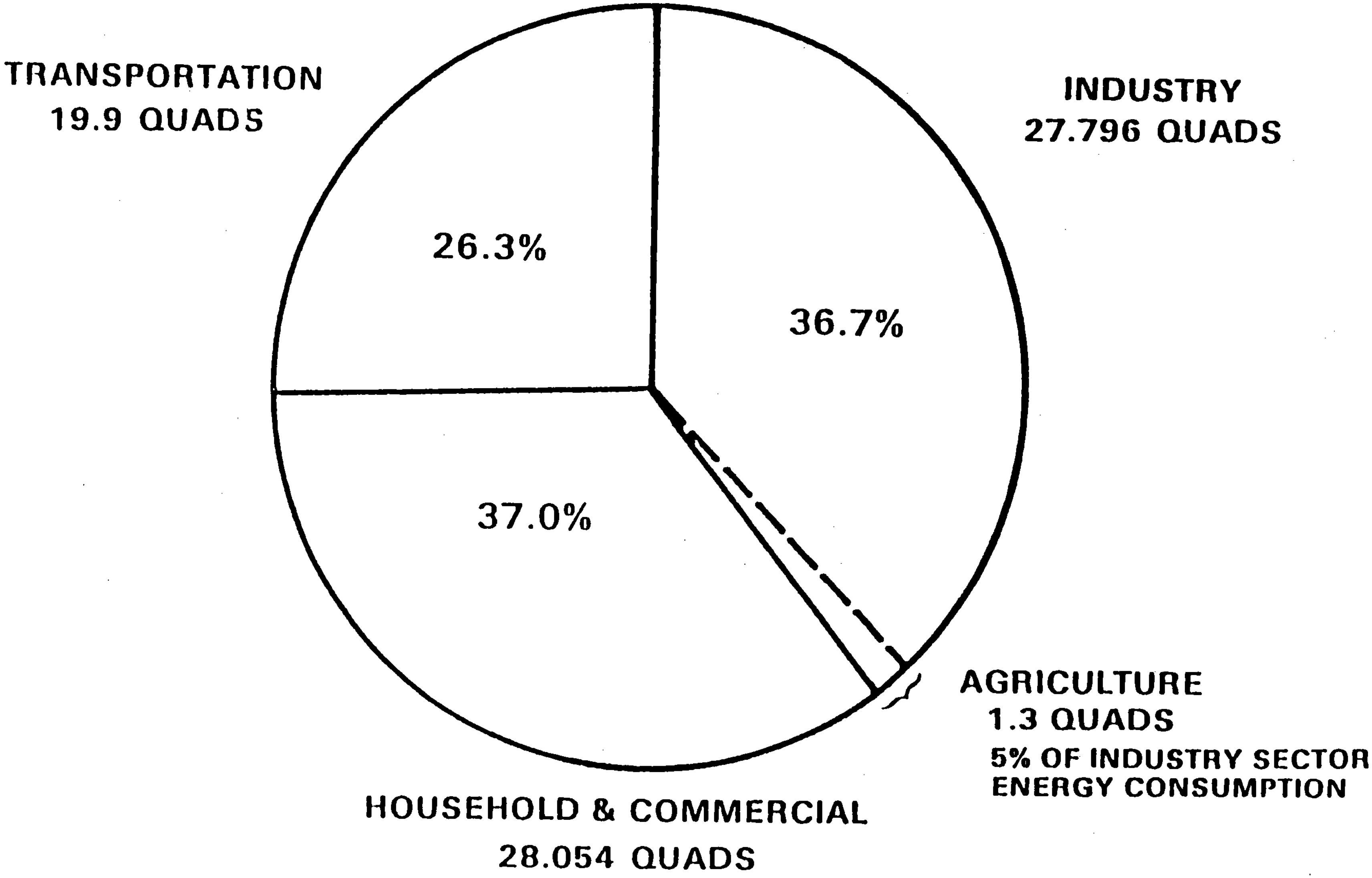
- Develop and recommend incentives
  - Make SIPH competitive with fossil fuels
  - Encourage use of solar
  - Stimulate mass production

4. Commercialization

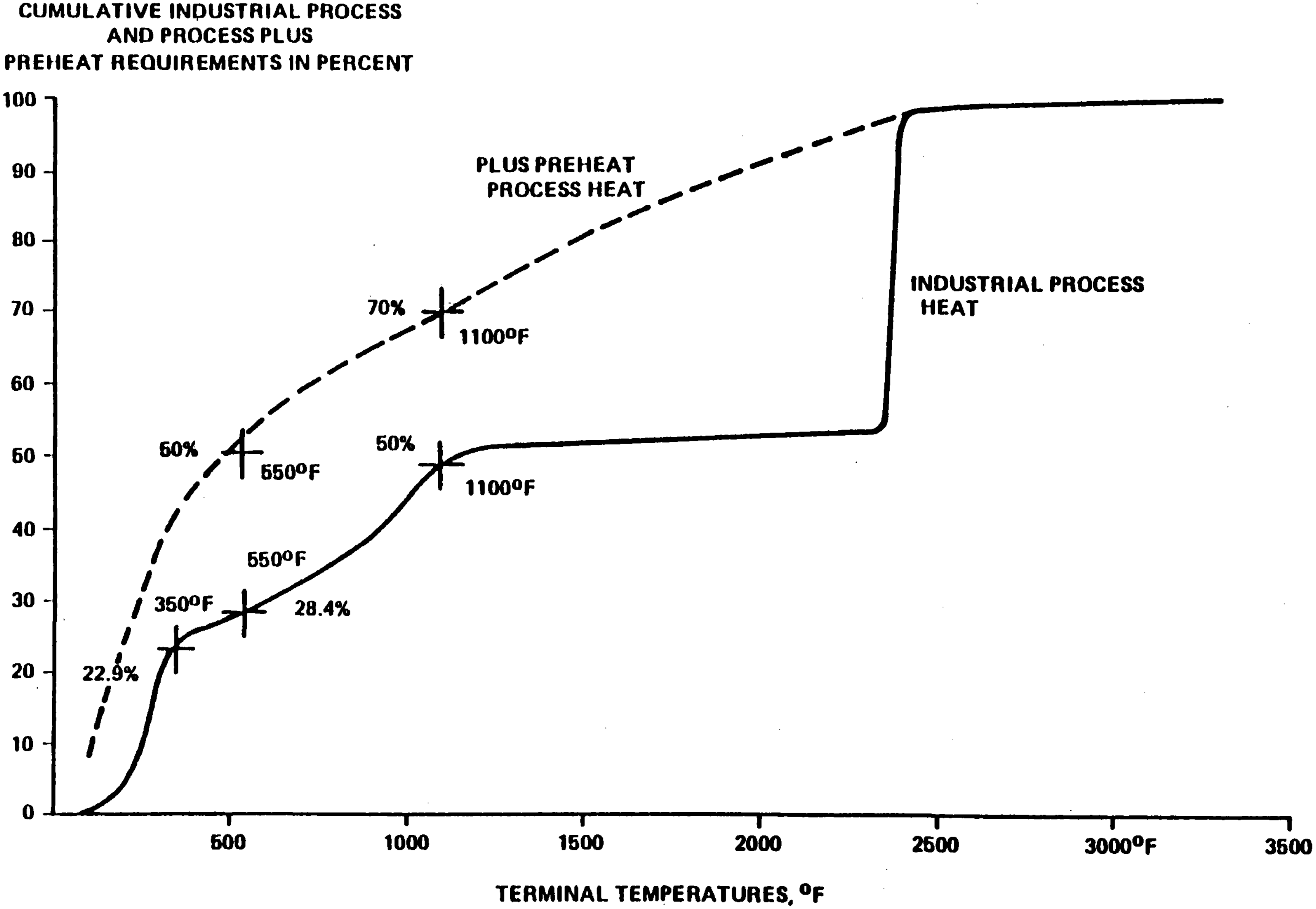
- Identify ideal applications; high insolation, favorable thermal load, adequate land, favorable financial position, regulatory incentives
- Information transfer

LS80-20638/4-12

UNITED STATES 1977 ENERGY CONSUMPTION BY MAJOR END USE SECTOR



TEMPERATURE SPECTRUM OF SURVEY DATA BASE INDUSTRIAL PROCESS AND PREHEAT REQUIREMENTS
0-3300^{o}F



SOLAR COLLECTOR TECHNOLOGY FOR AGRICULTURAL AND INDUSTRIAL PROCESS HEAT

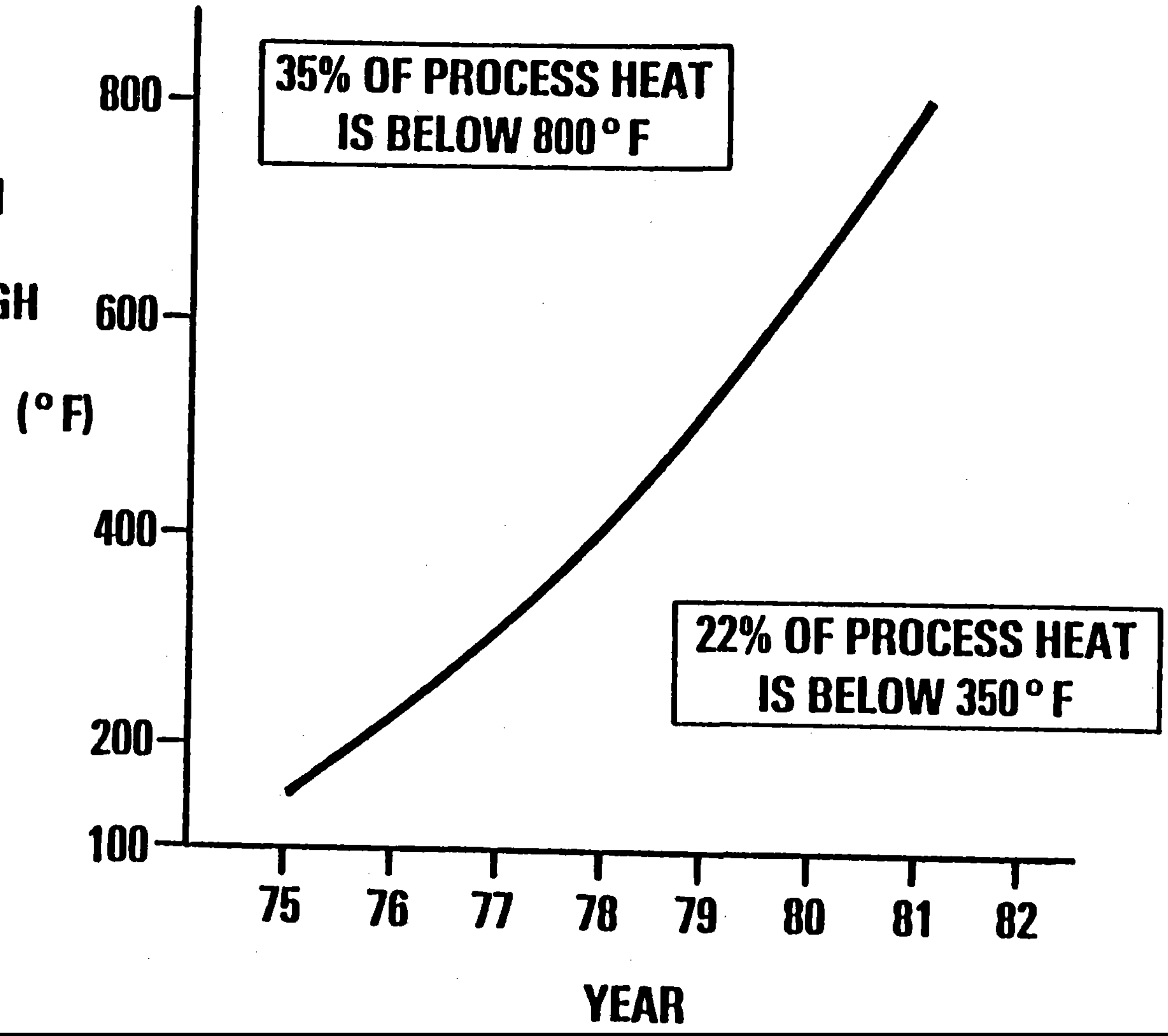
CONCENTRATORS

- PARABOLIC DISH
- PARABOLIC TROUGH
- CYLINDRICAL TROUGH
- FRESNEL
- CPC TROUGH

EVACUATED TUBE

FLAT PLATE

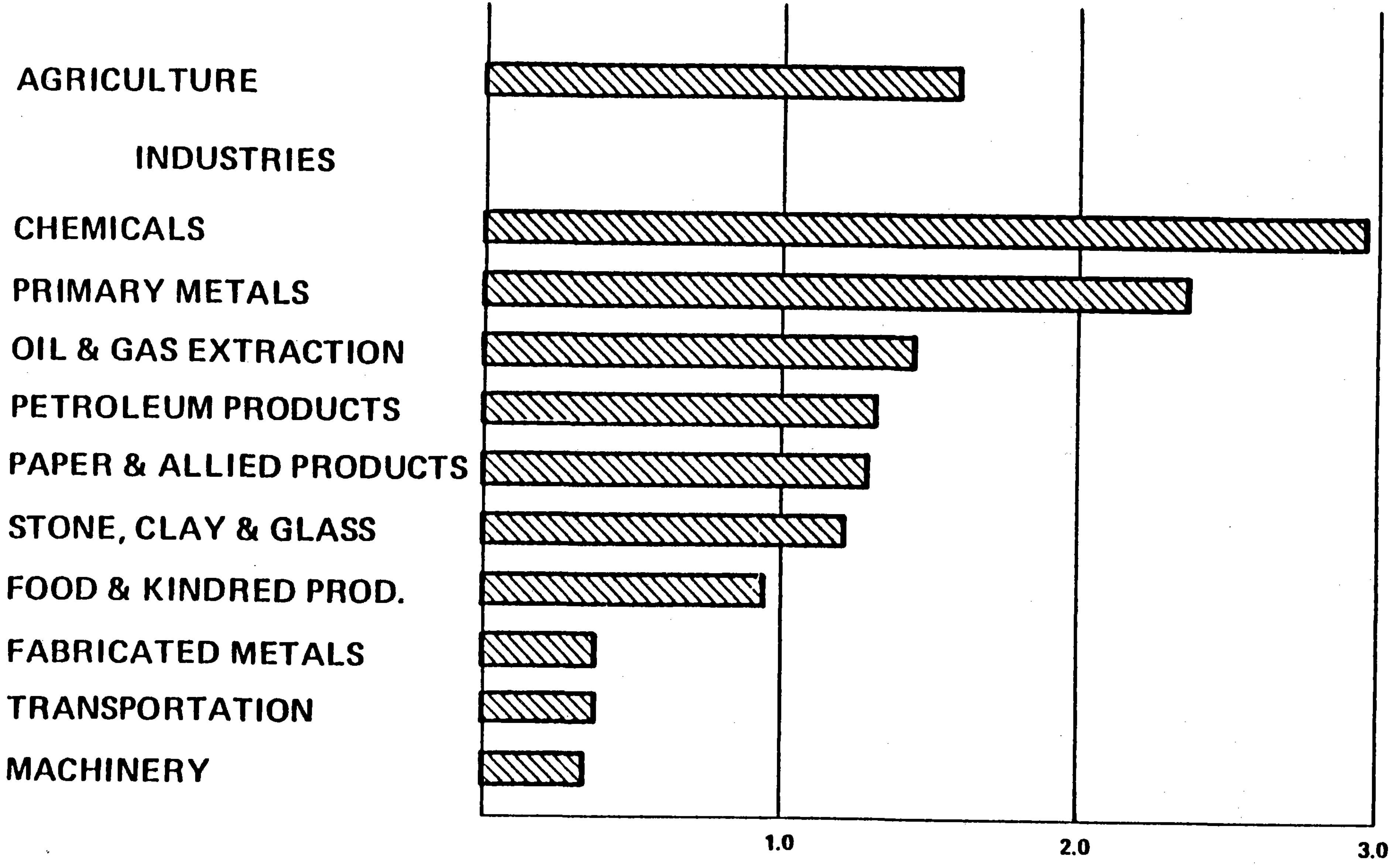
SHALLOW POND



35% OF PROCESS HEAT IS BELOW 800° F

22% OF PROCESS HEAT IS BELOW 350° F

ENERGY CONSUMPTION BREAKOUT



TOTAL ENERGY CONSUMED IN 1976 (QUADS = 10^{15}Btu)

ANNUAL SURVEY OF MANUFACTURERS, 1976

INDUSTRIAL PROCESS HEAT IS AN EXCELLENT SOLAR APPLICATION

ADVANTAGES

- **YEAR ROUND USE**
  3 TIMES AS EFFECTIVE
  AS HEATING APPLICATIONS
- **MINIMUM STORAGE**
  ENERGY USED AS PRODUCED
- **LARGE ARRAYS**
  ECONOMY OF SCALE
- **MAINTENANCE AVAILABLE**
  PERMITS MORE SOPHISTICATION
- **NO HEAT ENGINE REQUIRED**
  HIGHER EFFICIENCY
- **CENTRALIZED PURCHASE AUTHORITY**
  LOWER SALES COSTS

DISADVANTAGES

- **HIGHER TEMPERATURES**
  LOWER EFFICIENCY
- **INDUSTRIAL ENVIRONMENT**
  SURFACE CONTAMINATION
- **UNFAVORABLE ECONOMIC CRITERIA**
  TAXES, INVESTMENT

SIPH Systems Development Status

Accomplishments

- Moderate improvements in 2nd and 3rd cycle R&D trough collectors
- Identified needed improvements
- Moderate progress toward integrated collector modules

Remaining Challenges

- Impliment and test collector module improvements
  - Mass producible, improved performance, lower cost, longer life, higher reliability, lower installation cost
  - Every component needs improvement
  - More tests - improve - test - improve -- cycles
- Joint government/industry effort to make high quality, low cost sagged glass available

SIPH Demonstration Status

Accomplishments

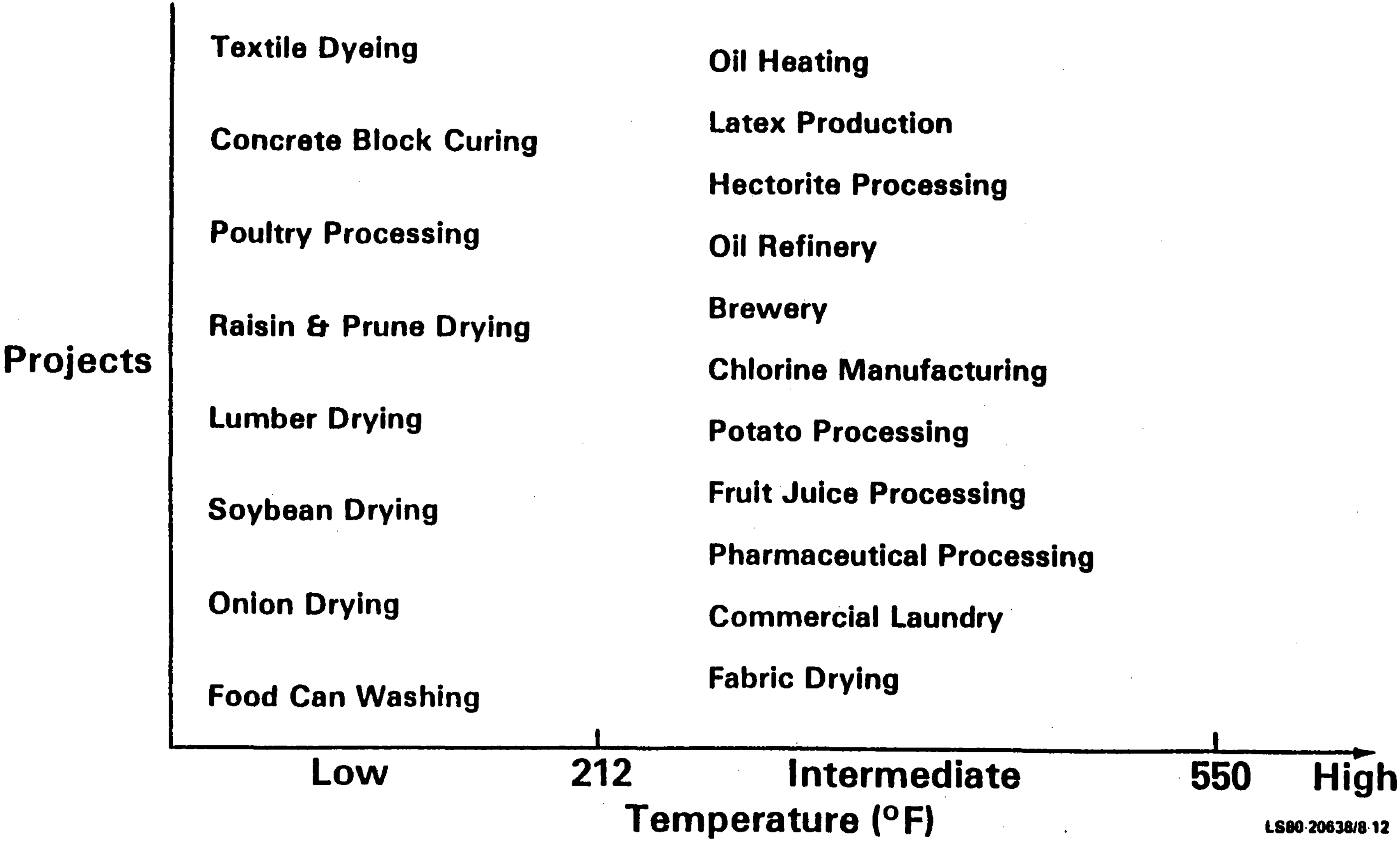
- Identified problems in integrating collectors into field test systems

Remaining Challenges

- Upgrade current demonstrations to field test quality with acceptable performance and data systems
- Develop federal assistance approaches which establish customer/supplier relationships between solar contractor and user
  - Meaningful cost data
  - Contractor responsibility
  - Support to companies that want to commercialize solar rather than sell to government
- Improve system reliability and data collection
- Demonstrate reliable long life systems

LS80-20638/6-12

Solar Industrial Process Heat Projects



Projects

- Textile Dyeing
- Concrete Block Curing
- Poultry Processing
- Raisin & Prune Drying
- Lumber Drying
- Soybean Drying
- Onion Drying
- Food Can Washing

- Oil Heating
- Latex Production
- Hectorite Processing
- Oil Refinery
- Brewery
- Chlorine Manufacturing
- Potato Processing
- Fruit Juice Processing
- Pharmaceutical Processing
- Commercial Laundry
- Fabric Drying

Low 212 Intermediate 550 High

Temperature (°F)

LS80-20638/8-12

Industrial Process Steam

(300°F — 550°F)

Contractor	Application	Location
Acurex Corporation	Heating Oil for Transport	Mobile, Alabama
Foster-Wheeler	Reaction Kettle & Steam Distillation	Dalton, Georgia
Jacobs Engineering Co.	Drum Dryers, Spray Dryers	Newberry Springs, California
Monument	Crude Oil Refining	Hobbs, New Mexico
Southwest Research Institute	Pasteurization, Sterilization	San Antonio, Texas
Stauffer Chemicals	Chlorine Caustic Processing	Henderson, Nevada
TRW	Potato Steam Fryers	Ontario, Oregon

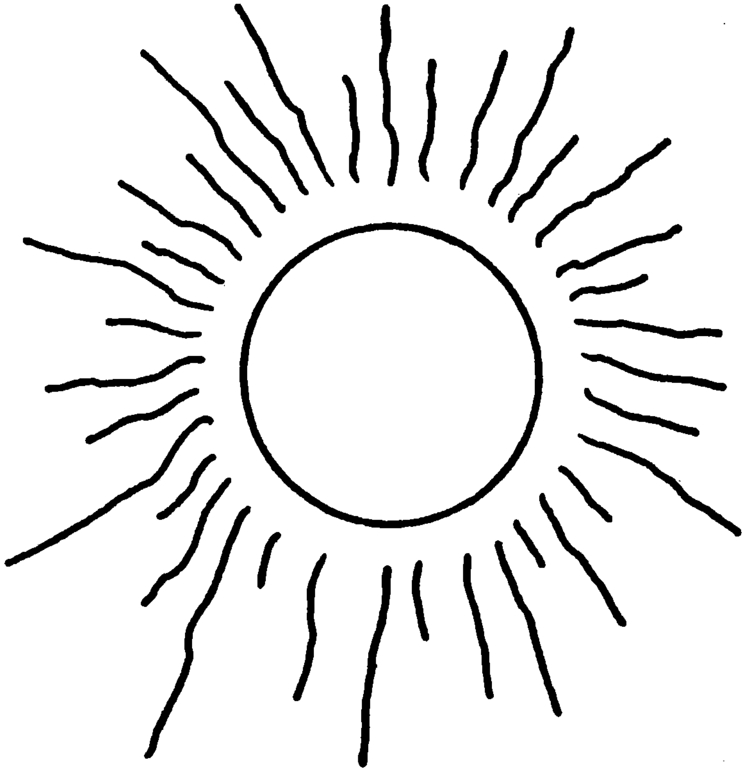
LS80-20638/12-12

Intermediate Temperature 212°-550° Field Test (Cost Shared)

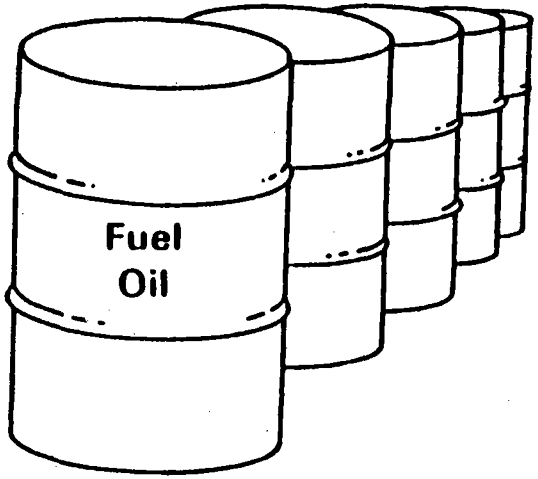
Proposer	Industrial Partner	Location	Size (Sq. Ft.)	Application
Columbia Gas	USS Chemicals	Ohio	50,000	Chemicals
Bates Container	Bates Container	Texas	34,720	Paper
SWRI	Caterpillar Tractor	Calif.	50,400	Manufacturing
Hilo Coast Processing Co.	Hilo Coast Processing Co.	Hawaii	50,400	Food Processing

Low Temperature (212°F) Field Tests Cost-Shared

- Request for Proposals (RFP): Issued June 29, 1979
- Requested Collector Field Size: 30,000-70,000 Ft^2
- Temperature Range: Up to 212°F at the Process
- Cost-Sharing Guideline: Goal of 50%
- Proposals Due: September 13, 1979
- Proposals Received: 13
- Status: Proposal Evaluation and Negotiation



Oil
from
Sunshine



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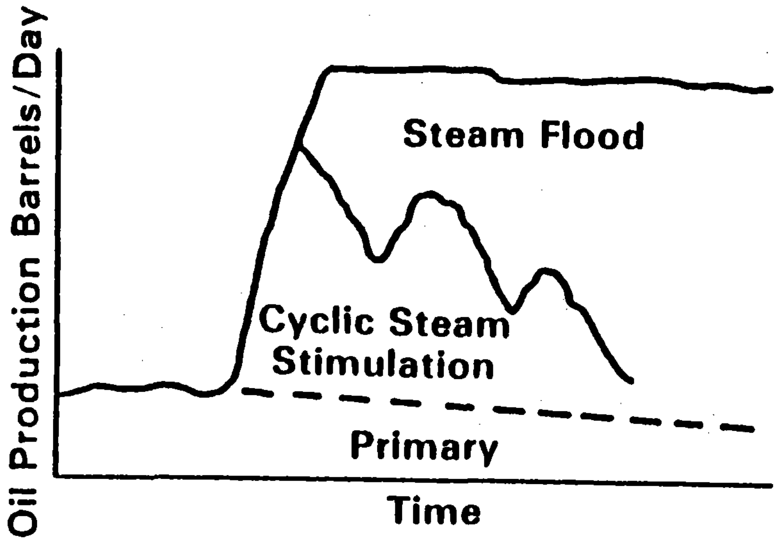
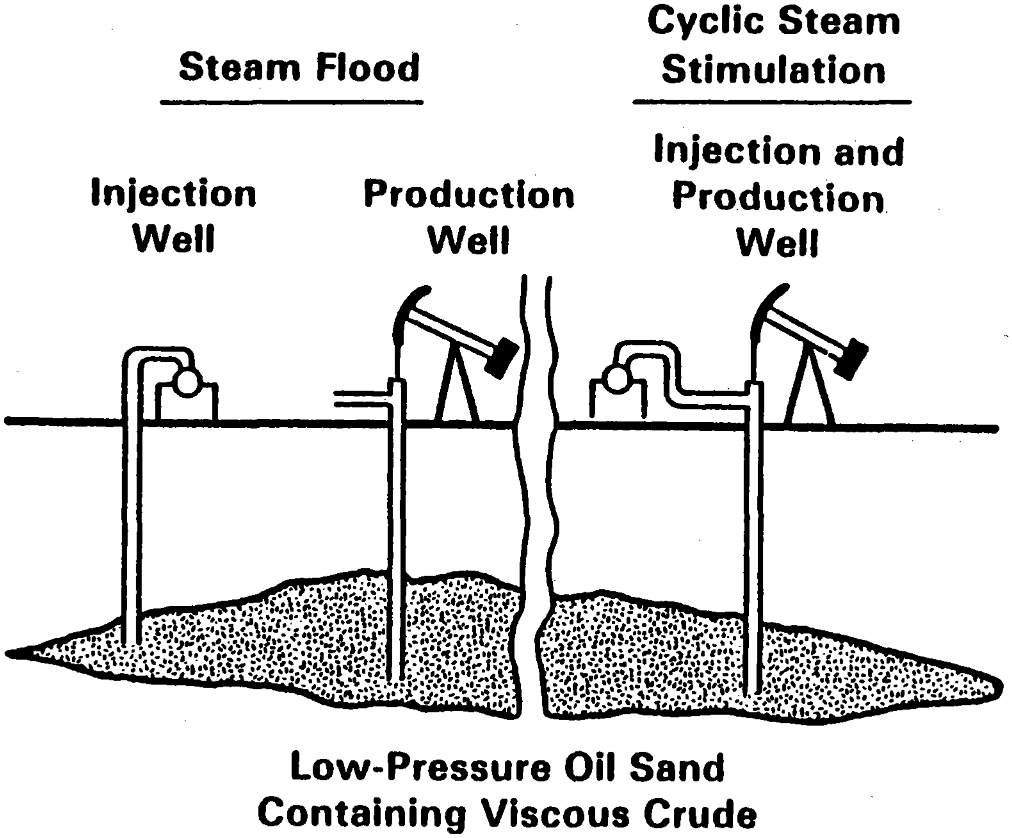
Recovery of Heavy Crude Using Steam





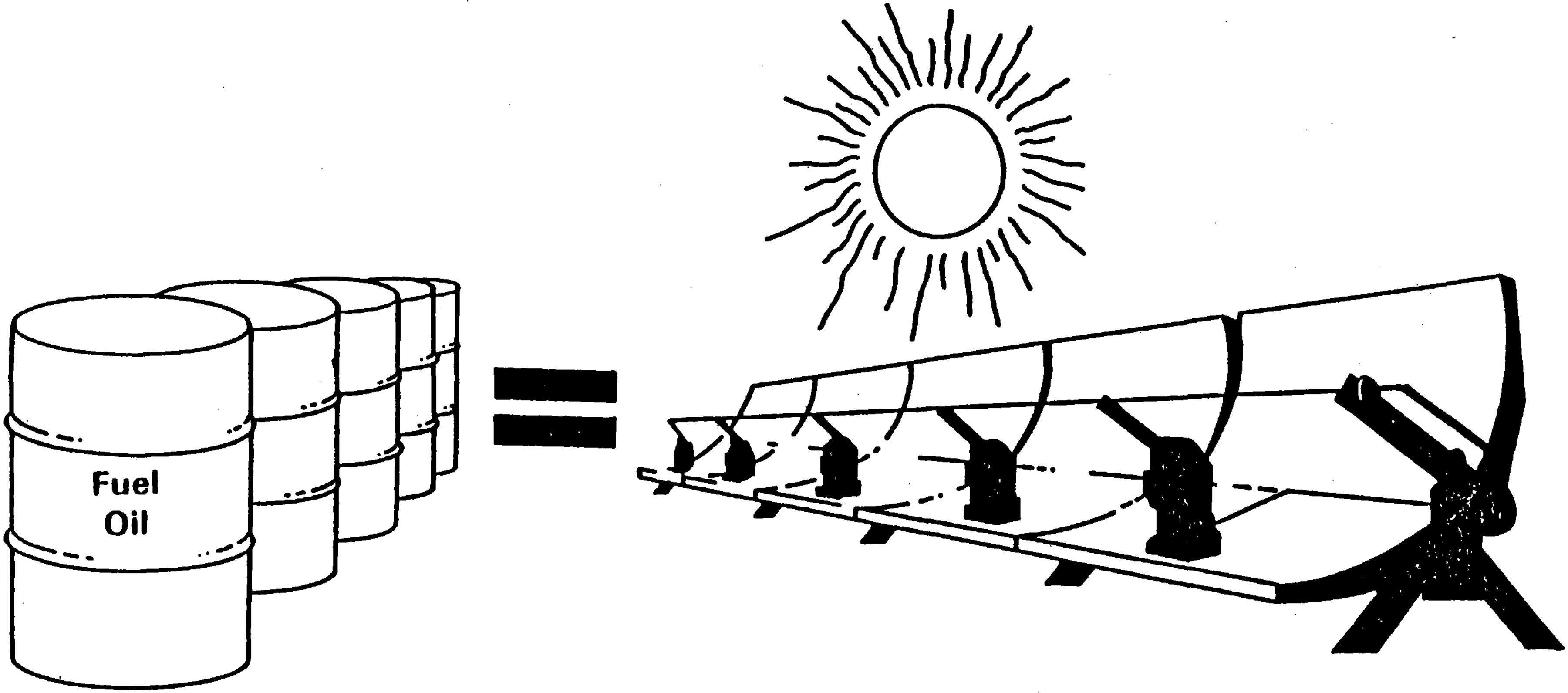
DM80/20146/5-16

Enhanced Oil Recovery Using Solar Energy

Background

- U.S. Oil Burning Steam Generator Systems Now Produce over 200,000 (100,000 Burned) Barrels/Day
- Known U.S. Heavy Viscous Crude Resource over 100 Billion Barrels
- Environmental Constraints Limit Additional Burning/ Expansion of Oil Recovery
- One-Third of Oil Recovered Currently Wasted in Steam Production
- Most Heavy Crude Reservoirs in Regions of High Insolation
- 350°F to 550°F Steam Required Is Feasible with Existing Solar Equipment

Solar Energy Potential As a Substitute for Fuel Oil Used by Present Steam Recovery Methods

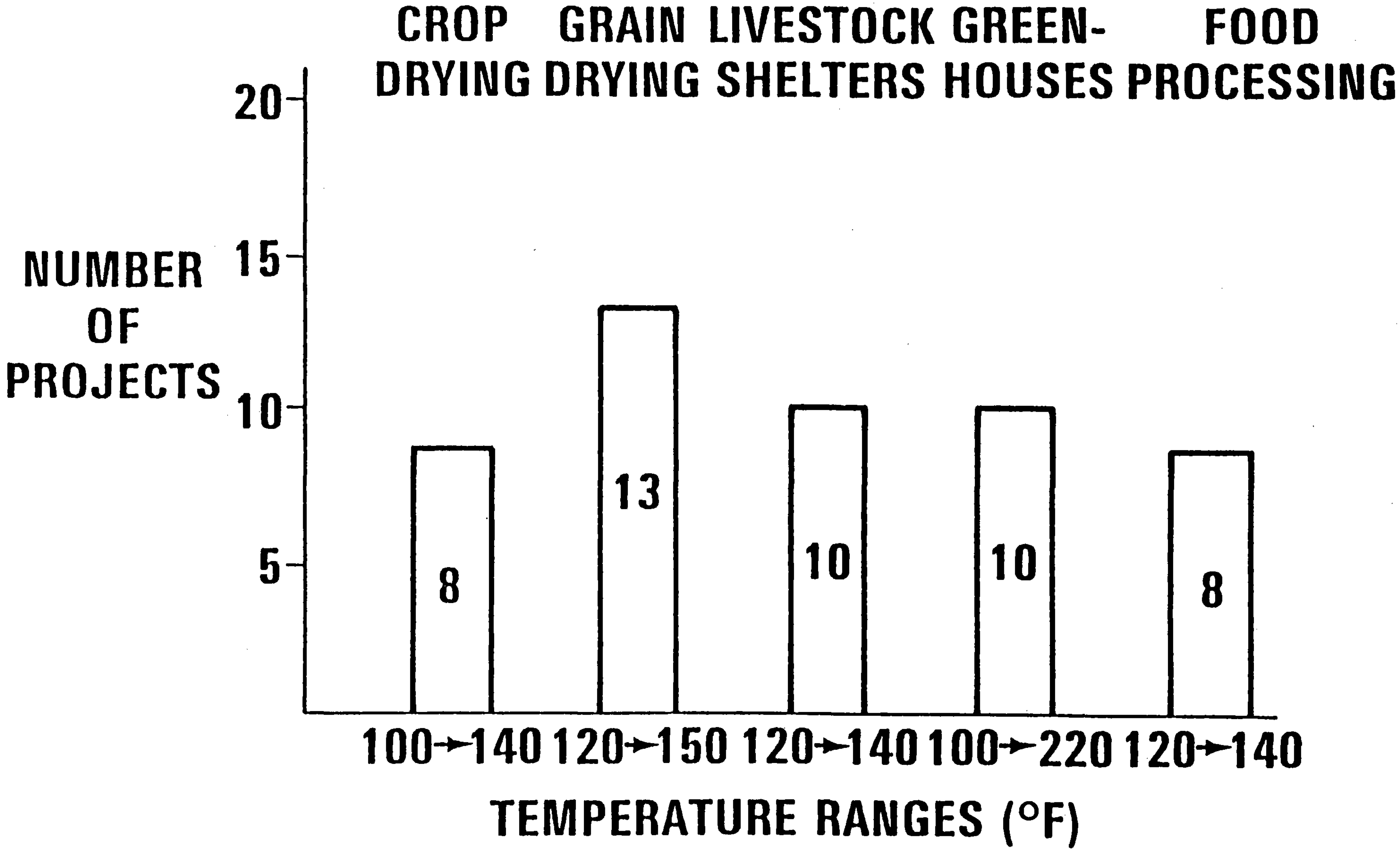


160,000 BBL/Day

960 Million Square Feet

*1 BBL Oil = 4.93 MBtu @ 85% Efficiency
1 Ft^2 of Collector Area Produces .3 MBtu/Yr

AGRICULTURAL PROCESS HEAT PROJECTS



SIPH COMMERCIALIZATION STATUS

ACCOMPLISHMENTS

- BEGINNING TO MAKE POTENTIAL USERS AWARE OF SOLAR
- IDENTIFIED EARLY ATTRACTIVE APPLICATIONS: HIGH INSOLATION, CONSTANT YEAR ROUND LOAD, MODERATE TEMPERATURES, WHERE 100% COAL OR GAS IS NOT FEASIBLE
  - EOR
  - OTHERS

REMAINING CHALLENGES

- PUBLICIZE CURRENT INCENTIVES
- HELP ACHIEVE ADVANCED SALES TO JUSTIFY MASS PRODUCTION
- DETAILED IDENTIFICATION OF POTENTIAL SIPH
- ENCOURAGE INTEREST IN PARTICIPATION OF FINANCIAL INSTITUTIONS
  - LEASING
  - 3RD PARTY OWNERSHIP SELLING STEAM

SIPH Incentive Status

Accomplishments

- Proposed ITC (All reimbursable)
  - 20% (10 + 10) may now be applicable
  - 25% through 1989 recommended by administration
  - Packwood Bill: 40% (10 + 30) to 0.5M then 30% (10 + 20) through 1989
- Fuel Use Act (Active now)
  - Annual 20% solar/80% gas or oil qualifies for exemption permitting use of oil or gas for new boilers over 100M Btu/hr (over 50M Btu/hr if new aggregate is over 250M Btu/hr)
  - 20% solar for 100M Btu/hr is approximately 750,000 ft^2
- Fuel priority (Pending - State cooperation required)
  - Gas: Higher priority during curtailment for solar users
  - Oil: Solar percent deducted from percentage curtailment (e.g. 25% solar, 30% curtailment yields 5% curtailment)

SIPH Incentive Status

(Continued)

Accomplishments

- Air quality (pending)
  - Solar output included in denominator for percent of input emissions limits
  - Solar/emissions trade offs
- EOR 75% front end capital (in place)
  - 75% billed allowable cost up to $20M per field per company is recoverable by selling controlled oil at uncontrolled prices
    - any percent ownership permits any distribution of benefits
  - Deregulation ends September 30, 1981 (Controlled oil may be scarce after January 31, 1981)

Remaining Challenge

- Get all pending incentives in place quickly
- Loan guarantee program (No known activity)
  - Needed program is similar to ship building guarantees

LS80-20638/9-12

Summary

- Current and pending laws and regulations could create a demand for a number of large SIPH systems (0.25 to 5M ft^2)
- No collector system now exists that should be installed in this scale
- Improvements, tests, and demonstrations of systems to meet this potential demand is urgently needed
  - Government role
  - Industry role

LS80-20638/11-12

Agenda
List of Participants

Solar Industrial Process Heat Conference

October 31 - November 2, 1979

San Francisco Bay Area

Oakland Hyatt House

AGENDA

October 30

7:00 - 9:00 p.m.	Registration	Oakland Room

October 31

7:30 - 8:00 a.m.	Registration Continental Breakfast	Oakland Foyer
8:00 - 9:00 a.m.	IPH TUTORIAL F. Kreith and C. Kutscher, SERI	Alameda Room
	Continental Breakfast	
9:00 - 9:30 a.m.	Registration (continued)	Oakland Foyer
	INTRODUCTORY SESSION David Kearney, Chairman SERI	Oakland Room
9:30 - 9:45 a.m.	Conference Overview David Kearney	
9:45 - 10:40 a.m.	Overview of DOE Programs M. Davis, J. Rannels	
10:40 - 11:00 a.m.	BREAK	Oakland Foyer
	EXPERIENCE FROM IPH FIELD TESTS William Auer, Chairman DOE	
11:00 - 11:25 a.m.	Hot Water Projects W. Nettleton, DOE San Francisco Operations Office	
11:25 - 11:50 a.m.	Hot Air Projects W. Dickinson, LLL	
11:50 - 1:15 p.m.	LUNCH	Alameda Room
1:15 - 1:35 p.m.	Low Temperature Steam Projects G. Gerich, LLL	Oakland Room
1:35 - 1:55 p.m.	Intermediate Temperature Steam Projects J. Mills, INEL	
1:55 - 2:15 p.m.	Privately Funded Projects A. Casamajor, LLL	

2:15 - 2:35 p.m. New DOE Projects
J. Greyerbiehl
DOE

2:35 - 3:00 p.m. BREAK Oakland Foyer

3:00 - 6:00 p.m. <u>POSTER SESSION</u> - J. Mills, INEL and J. Leonard, Sandia
Co-Chairman

CONTRIBUTED POSTERS Alameda Room
CONTRACTOR'S POSTERS Hayward Room

ASSIGNED PRESENTATION TIME
3:00 - 4:30 p.m. Odd Numbers
4:30 - 6:00 p.m. Even Numbers

<u>CONTRIBUTED POSTER SESSION</u> Alameda Room

1. An Economic Analysis of a Solar Industrial Process Steam System
   D. J. Allen, A. C. Gangadharan, G. D. Gupta
   Foster Wheeler Development Corporation

2. Screening Potential Industrial Applications of Solar Energy
   K. D. Bergeron, Sandia Laboratories - Albuquerque

3. Industrial Applications Analysis: Market Characterizations and System Definition for Several Industries
   K. C. Brown, P. A. Ketels, S. A. Stadjuhar
   Solar Energy Research Institute

A Comparative Analysis of Solar Thermal Systems for On-Site Industrial Applications Cancelled
Rebecca Bjustrom and Richard Manley
The MITRE Corporation/Metrek Division

4. Reliable Commercial Tracker for Line-Focusing Collectors
   Richard J. Carlton, Acurex Corporation

5. Solar-Industrial Heat for New York State - A Case Study in Regional Impact on Economic Viability
   E. S. Cassedy, Solar Energy Applications Center/Polytechnic Institute of New York

Solar Process Heat for Drying Coal, Peat and Waste Sludge Cancelled
R. E. Dame, Mega Engineering

6. Performance and Cost Advantages of a Solar-Assisted Industrial Heat Pump System
   Richard T. Duncan and Gordon J. Van Zuiden
   Westinghouse Electric Corporation

7. Solar Ponds for Industrial Process Heat
   M. Edesess, K. Brown, T. S. Jayadev
   Solar Energy Research Institute

8. Case Studies of Potential Solar Industrial Process Heat Applications
   Douglas W. Hooker and Ronald E. West
   Solar Energy Research Institute

9. GRI's Solar Augmented Applications and Industry Program
   Vincent B. Fiore, Gas Research Institute

10. Research and Development Priorities for Parabolic Trough Concentrating Collectors
   R. C. Gee, H. W. Gaul and D. W. Kearney
   Solar Energy Research Institute

11. Effect of Cleaning Cost on Process Heat from Line Focus Solar Collectors
   L. L. Lukens and W. P.Schimmel, Jr.
   Sandia Laboratories - Albuquerque

12. Insights and Experiences from the DOE/Sandia Midtemperature Solar Systems Test Facility
   W. H. McCulloch, Sandia Laboratores - Albuquerque

13. Solar Economizers: The Potential for Solar Feed-Water Preheating in IPH Applications
   Albert F. Naccach, ATON Solar Manufacturers
   James V. Goins, BRYAN Steam Corporation

14. Low Temperature Industrial Process Heat from Non-Convecting Solar Ponds
   T. L. Ochs and J. O. Bradley, Desert Research Institute

15. Sandia/DOE Solar Total Energy Test Facility
   J. V. Otts, Sandia Laboratories - Albuquerque

16. Preliminary Definition and Characterization of a Solar Industrial Process Heat Technology and Manufacturing Plant for the Year 2000
   Ted Prythero and Richard T. Meyer
   Western Energy Planners, Ltd.

17. The Implications of President Carter's 20% Solar Goal on the Development of Industrial Process Heat Systems
   Michael Shulman, The MITRE Corporation/Metrek Division

18. Solar Supplement to Laundry Drying
   C. C. Smith, Solar Energy Applications Laboratory/
   Colorado State University

19. The Potential for Solar Application for Process Heat in Arizona
   Stephen E. Smith, Leonel P. Campoy, Jay Lobit, Rocco Fazzolare
   University of Arizona, Energy Management & Policy Group

20. Parabolic Trough/Flat Plate Collector Performance Comparison
   G. W. Treadwell, Sandia Laboratories - Albuquerque

21. Central Receiver Solar Energy System for an Oil Refinery
   F. J. Zoschak and R. E. Sommerlad, Foster Wheeler Development Corporation, and J. E. Rogan, McDonnell Douglas Astronautics Company

CONTRACTOR'S POSTER SESSION Hayward Room

HOT WATER

1. One Year of Operating Experience at the Campbell Soup Solar Hot Water Facility
   Stanley B. Youngblood and David Swartz, Acurex Corporation

2. Solar Industrial Process Hot Water for Concrete Block Manufacture
   H. A. Wilkening, AAI Corporation

3. Operational Results of the LaFrance, South Carolina, Solar Process Hot Water System
   J. B. Trice, J. Herz, and R. C. Burns, General Electric Co.

HOT AIR

4. An Analysis of the Operation of an Industrial Drying Solar System
   E. J. Carnegie, P. W. Niles, W. B. Stine
   California Polytechnic State University

5. LaCour Kiln Service (No abstract received)
   Paul O. McCormick,Lockheed Missiles & Space Co., Inc.

6. Solar Augmented Soybean Drying
   Bill R. Hall, Teledyne Brown Engineering

7. Application of Solar Energy to the Dehydration of Onions and Garlic Gilroy Solar Project - Initial Operation and Evaluation
   B. J. Graham, P. D. Sierer, Jr., Trident Engineering Associates
   and David Powell, Gilroy Foods Company

LOW TEMPERATURE STEAM

8. Textile Drying at Westpoint Pepperell Using Solarized Can Dryers
   P. D. Mitchell, Honeywell Energy Resources Center

9. Construction of a Solar Industrial Process Steam System for the Johnson & Johnson Manufacturing Plant
   W. G. Boeck and R. Harper, Acurex Corporation

10. Home Laundry Co. (No abstract received)
    Bernard G. Eldridge, Jacobs-Del Solar Systems, Inc.

11. Solar Production of Low Pressure for Processing of Orange Juice
    J. B. Trice, et.al., General Electric Company

INTERMEDIATE TEMPERATURE STEAM

12. Design and Analysis of a Solar Industrial Process Heat System for Ergon, Inc.
    J. Kull, M. Matteo and A. K. Yasuda, Acurex Corporation

13. Systems Analysis of a Solar Industrial Process Steam Concentrating System
    G. D. Gupta, A. C. Gangadharan, G. Bhayana
    Foster Wheeler Development Corporation

14. National Lead Industries (No abstract received)
Bernard G. Eldridge, Jacobs-Del Solar Systems, Inc.

15. Solar Energy in the Oil Patch
L. D. Clark,Monument Solar Corporation

16. Solar Production of Industrial Process Steam for the Lone Star Brewery
Danny M. Deffenbaugh, Southwest Research Institute

17. A Concentrating Collector System Designed for the Stauffer Chemical Corporation in Henderson, Nevada
Harry T. Whitehouse, Michael Kast and Patricia Ortiz
Pacific Sun, Inc.

18. Solar Production of Industrial Process Steam for Potato Frying
Jack Cherne, TRW Energy Systems

4:30 - 6:00 p.m.	Cash Bar in parallel with Poster Session	Alameda Foyer

November 1

8:00 - 8:30 a.m.	Continental Breakfast	Oakland Foyer
	TECHNOLOGY ASSESSMENT - I James Rannels, Chairman DOE	Oakland Room
8:30 - 8:55 a.m.	Solar Ponds S. Sargent, DOE/SERI Site Office	
8:55 - 9:20 a.m.	Line Focus Concentrators J. Banas, SLA	
9:20 - 9:45 a.m.	Point Focus Concentrators J. Lucas, JPL	
9:45 - 10:10 a.m.	Central Receiver Systems J. Fish, SLL	
10:10 - 10:30 a.m.	BREAK	Oakland Foyer
	TECHNOLOGY ASSESSMENT - II Sheldon Gordon, Chairman Chilton Engineering	Oakland Room
10:30 - 11:00 a.m.	Materials Considerations B. Butler, SERI	
11:00 - 11:30 a.m.	Storage E. R. Furman, NASA Lewis	
11:30 - 12:00 Noon	System Configurations H. Whitehouse, Pacific Sun	
12:00 - 1:00 p.m.	LUNCH	Alameda Room

	ECONOMICS SESSION Ab Davis, Chairman JPL	Oakland Room
1:00 - 1:30 p.m.	Economics Methodology W. Dickinson, LLL	
1:30 - 2:00 p.m.	Goals & Incentives K. Brown, SERI	

WORKING GROUPS - Vern Rees, Chairman - Suntec

2:00 - 2:15 p.m.	Working Group Objectives V. Rees	
2:15 - 2:30 p.m.	BREAK	Oakland Foyer
2:30 - 5:30 p.m.	Working Group Meetings*	Rooms to be posted

WORKING GROUP TITLES	PANEL MEMBERS
1. Near Term IPH Markets	Pete Ketels, SERI (Chairman) John Shafer, Acurex Jim Rogan, McDonnell-Douglas
2. Costs and Incentives	Ab Davis, JPL (Chairman) Loren Hov, Stauffer Chemical Gus Hutchison, Solar Kinetics
3. System Configuration and Plant Interface Problems	Jim Castle, SERI (Chairman) Bernard Eldridge, Jacobs Ray Ogle, Johnson & Johnson
4. Microprocessor Controls	Howard Gerwin, Sandia (Chairman) Jim Williams, Honeywell Art Schwartz, Consultant
5. Hardware Development Needs	Jim Banas, Sandia (Chairman) Manny Delgado, DEL Mfg. Joe Buggy, Westinghouse
6. High Temperature IPH	Jim Fish, Sandia (Chairman) Howard Webb, Aerospace Corp. James Graf, General Electric

November 2

8:00 - 8:30 a.m.	Continental Breakfast	Oakland Foyer
8:30 - 10:00 a.m.	Industry User Panel R. Barbieri, Chairman JPL	Oakland Room
10:00 - 10:15 a.m.	BREAK	Oakland Foyer
10:15 - 11:15 a.m.	Working Group Reports V. Rees, Chairman	Oakland Room
11:15 - 11:45 a.m.	DOE IPH Plans & Closing Remarks J. Dollard, DOE	

*It is hoped that all conference attendees will participate in the working groups. The panels will facilitate the discussions.

Industry User Panel Members

1. Eric Burnett	ARATEX Services Inc. Encino, CA
2. Charles Strong	Johnson & Johnson Sherman, TX
3. James Trice	General Electric Philadelphia, PA
4. Harold Wilkening	AAI Baltimore, MD

SOLAR INDUSTRIAL PROCESS

HEAT CONFERENCE

October 31 - November 2, 1979

Oakland, California

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