The U.S. Department of Energy Solar Thermal Energy Systems Program

An Overview Presentation
by Gerald W. Braun

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THE U.S. DEPARTMENT OF ENERGY SOLAR THERMAL SYSTEMS PROGRAM

AN OVERVIEW PRESENTATION AUGUST 1979

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SECTION 1.0

INTRODUCTION

The following paper was developed as a speech for the Solar Energy Industries Association at their meeting in San Jose, California, 9 August 1979. Intended as both a position paper and a progress report to industry, this document provides one of the most comprehensive overviews of the U.S. Department of Energy's Solar Thermal Program.

Cost goals, systems design parameters, applications considerations, and the potential for industry involvement in solar thermal development and commercialization are described in detail. Decentralized management of R&D functions is linked to priorities and strategies of the evolving program.

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SECTION 2.0

DOE SOLAR THERMAL ENERGY SYSTEMS PROGRAM OVERVIEW

The DOE Solar Thermal Energy Systems Program supports development of concentrating mirror/lens heat collection and conversion technologies, for both centralized and dispersed applications. 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. Photovoltaic electric systems using concentrating mirrors also draw on the technology base being established in this program. The concentration of sunlight is necessary for applications requiring temperatures above 2500°F. It appears that thermal concentrator systems may be economically preferable to flat-plate systems in many lower temperature applications as well.

Concentrator systems utilizing conventional materials (glass, steel and concrete) can produce heat from solar radiation over a range of temperatures, from ambient to 2500°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 (Fig. 2-1).

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 inexpensive 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.

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.

2.1 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. Consequently, work on thermal, collector, and system technologies gained early momentum. The solar thermal program reached a level of approximately $100 million per year in FY78 and FY79. Its funding history is indicated in Table 2-1.

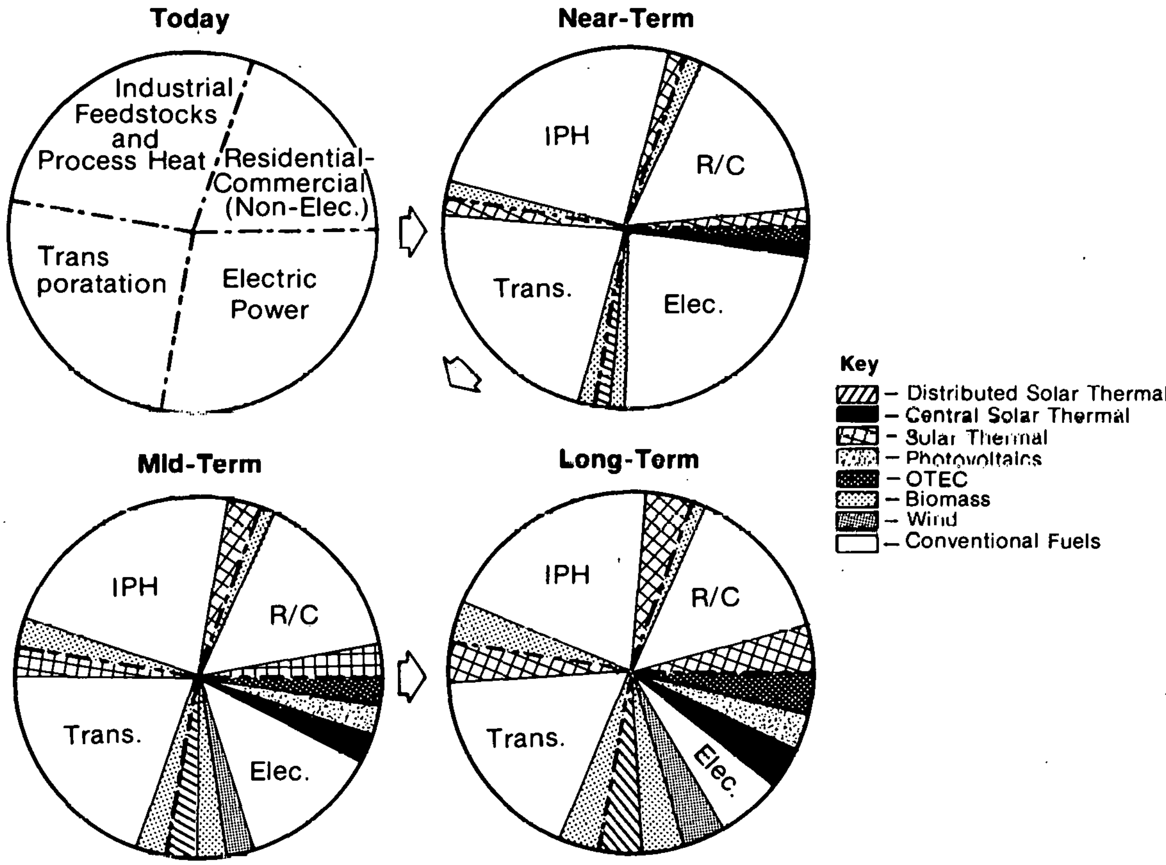

Figure 2-1. Market Potential

Table 2-1. SUMMARY OF SOLAR THERMAL FUNDING

(In Millions of Dollars)

	FY75	FY76 and Transition Qtr.	FY77	FY78	FY79	FY80
Large Power	13.2[b]	26.9[b]	21.5	21.8	27.0	64.1[a]
Small Power			20.1	28.1	28.0	33.5[a]
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

[a]Includes Capital Equipment/Construction Funding

[b]Classified as R&D funds under ERDA

DOE's new program management structure provides clear boundaries for decentralized management and organization. (See Fig. 2-2.) This structure allows research and development activities for each concentrator approach to be prioritized within a clearly defined budget. Although industry is strongly urging the delay of narrowing technical options within the concentrator programs until critical technical issues are resolved for each subsystem, in all cases the new structure provides the most comfortable framework for making necessary programmatic decisions.

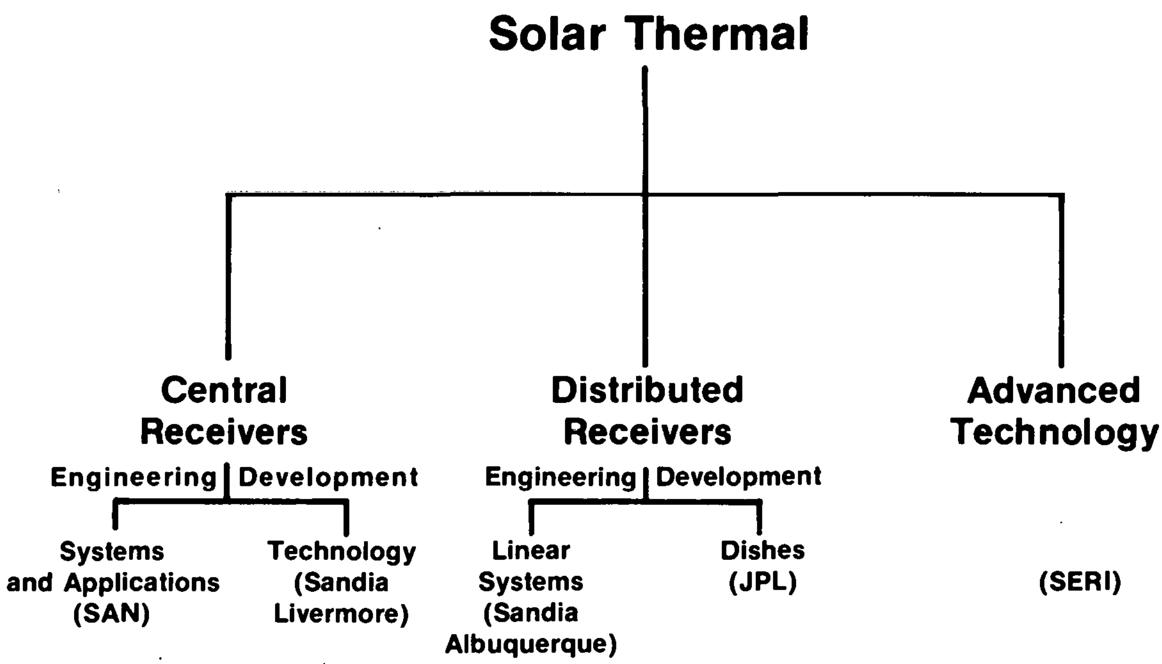

Figure 2-2. Program Organization

Priorities among concentrator options can be established based on assessments of the best market opportunities and potential energy displacement impact of the 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.

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 to better define system costs and technical capabilities needed to penetrate key markets. Studies will also 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.

2.2 MARKETS

Anticipating budget constraints and the resulting difficult decisions, 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 less exact. 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. 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. For industrial heat, an onsite fossil backup 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 backup.

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:

- user's financial decision-making criteria;
- relative uniformity of size and technical requirements, (at stake is the degree of system and component standardization that is possible and the amount of special design effort required for each project);
- land cost and availability for both retrofit and new installations;
- capital formation capability of potential users;
- relation of market size and growth to geography;

- cost and availability of conventional fuels; and
- applicable regulator and tax constraints.

2.3 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. 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 through 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 under way to define appropriate second-generation critical system experiments and engineering demonstrations. Application experiments are selected to provide experience in markets of early opportunity and are 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.

2.4 GOALS

Consistent with penetrating major energy markets, cost goals for all concentrator systems have been established. In general, 1990 goals (in 1980 dollars) are in the range of \$1,000-2,500/kW, depending on system capacity factor and credits for heat production. This approximately equals \$5/MBtu for heat. When established, goals for fuel derived from thermochemical processes will be in the range of $5-10/MBtu. 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 $7-10/ft^2 by 1990 and 25-50% lower by the year 2000. System and subsystem goals are now under review by the Solar Thermal Cost Goals Committee 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.

SECTION 3.0

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 Laboratories 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.

3.1 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 storms of skepticism. Claiming 30% of the program's three-year budget between FY78 and FY80, the project has been subjected to high level technical review, management audit, and deferral. It has survived intact because:

- economic prospects for central receivers look increasingly favorable as experience accumulates and cost estimates are firmed up;
- the management approach established by DOE's San Francisco Operations (SAN) Office is sound; and, most importantly,
- 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. Design and operating experience will be provided with an integrated plant that cannot be simulated with even the most powerful analytical tools. The project reached a critical point this fall when preliminary design efforts were completed, cost estimates became available, and bids for heliostats were evaluated. Selection of the heliostat supplier (Martin Marietta) was made based on these criteria and tests of preproduction prototypes at the Central Receiver Test Facility (CRTF) near Albuquerque, New Mexico (see Fig. 3-1).

3.2 REPOWERING

The repowering concept, as illustrated in Fig. 3-2, was originally introduced by the Public Service Company of New Mexico. It has captured the interest and imagination of southwestern electric utilities and 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, the program is responsive to the provisions of the National Energy Act, which constrains oil and natural gas use in large utility and industrial boilers.

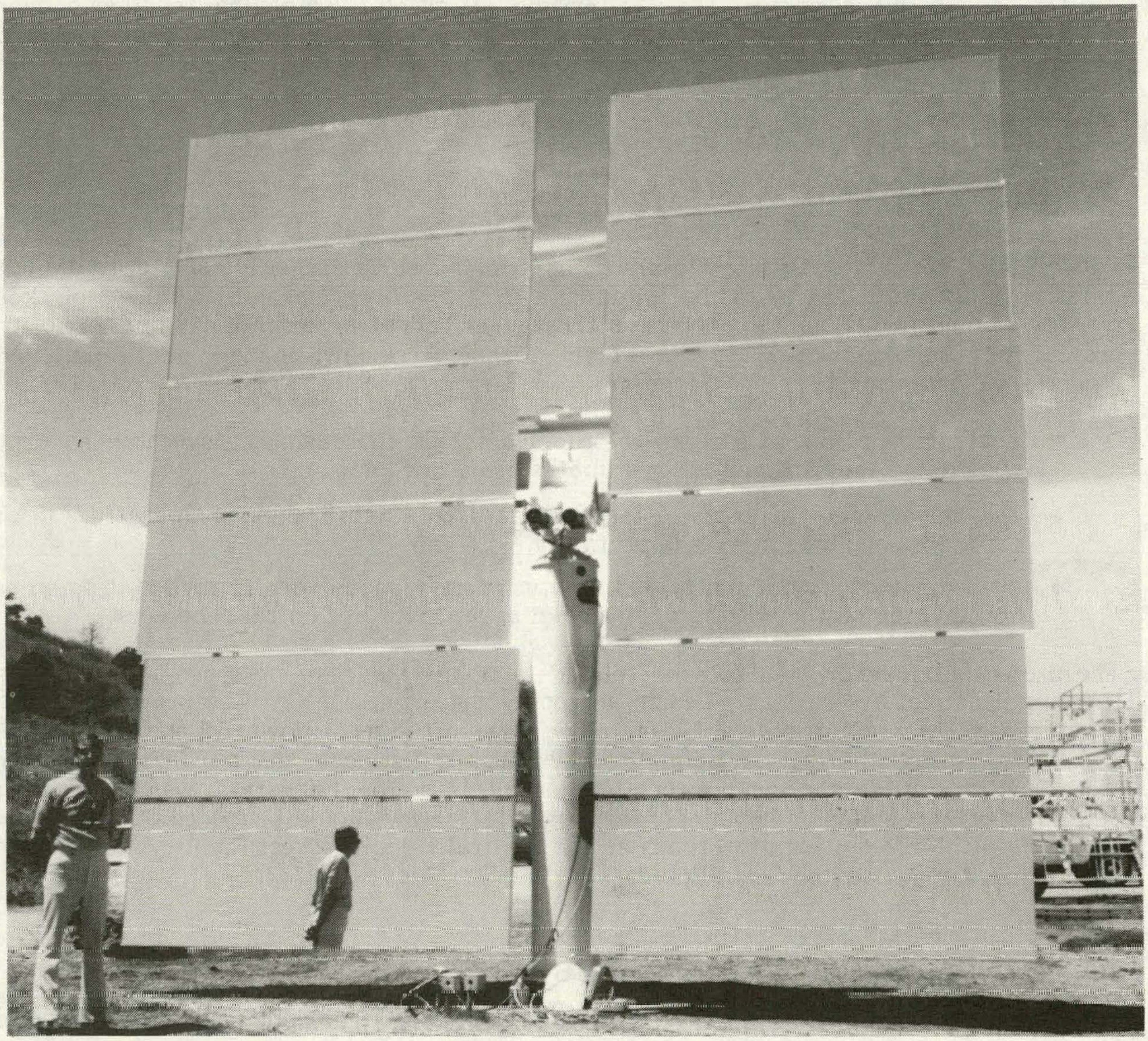

Figure 3-1. Barstow Heliostat

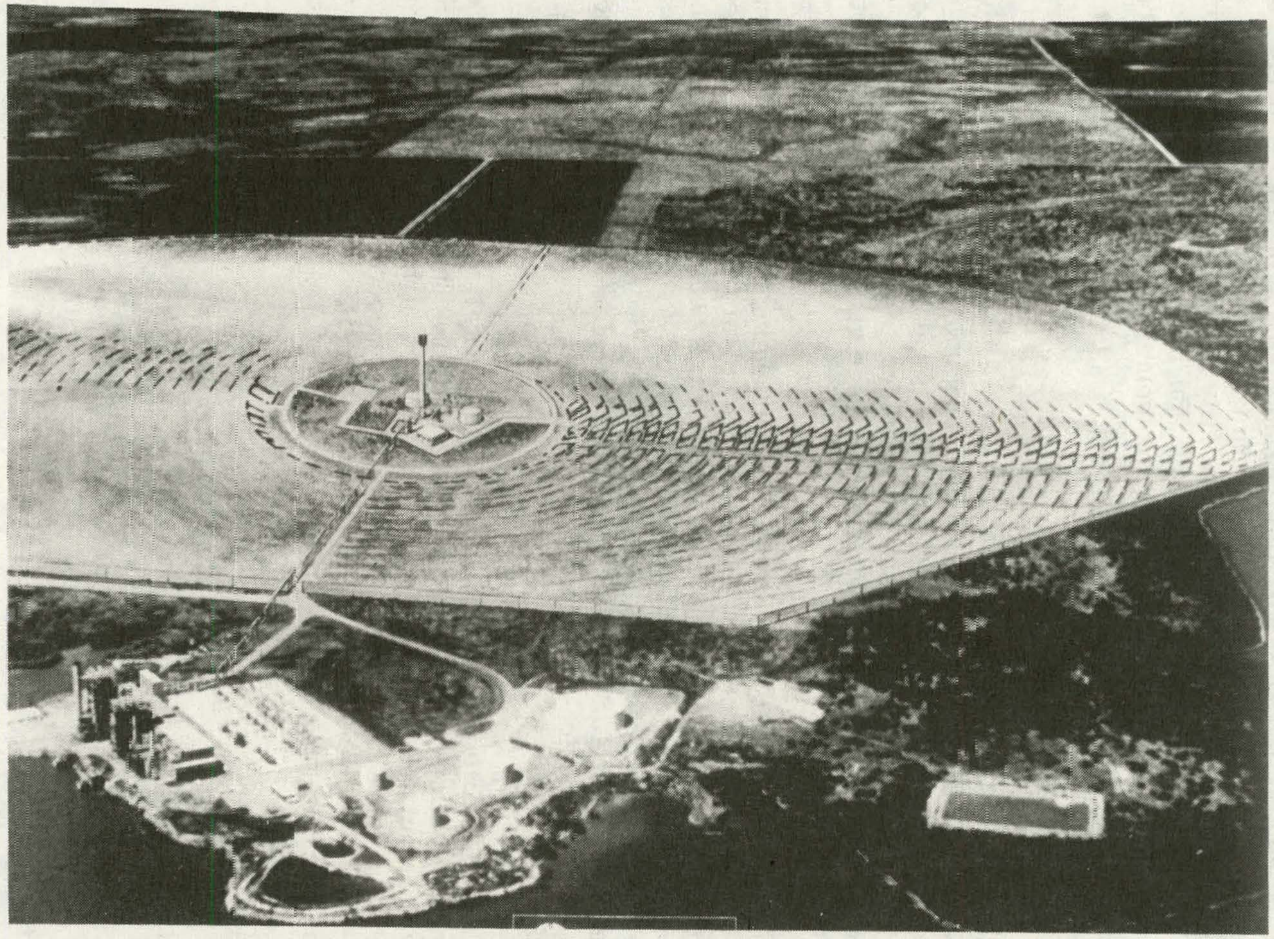

Figure 3-2. Repowering (Artist's Concept)

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 awarded in September 1979 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 FY79 contracts to develop and test mass producible heliostat designs by FY81. A program opportunity notice to select repowering/retrofit projects for construction is planned for FY80. Such projects should provide an initial heliostat market base with no direct federal involvement in heliostat production.

3.3 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 approximately $25 million per year. Management of systems and applications related efforts has been delegated to the DOE SAN Office. Sandia Laboratories at Livermore provides technical management support to SAN. Management of component (heliostat and receiver) development efforts has been delegated directly to Sandia.

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 backup 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 efforts 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°-2000°F range; the first of which was put through a highly successful series of tests at CRTF, as shown in Fig. 3-3.

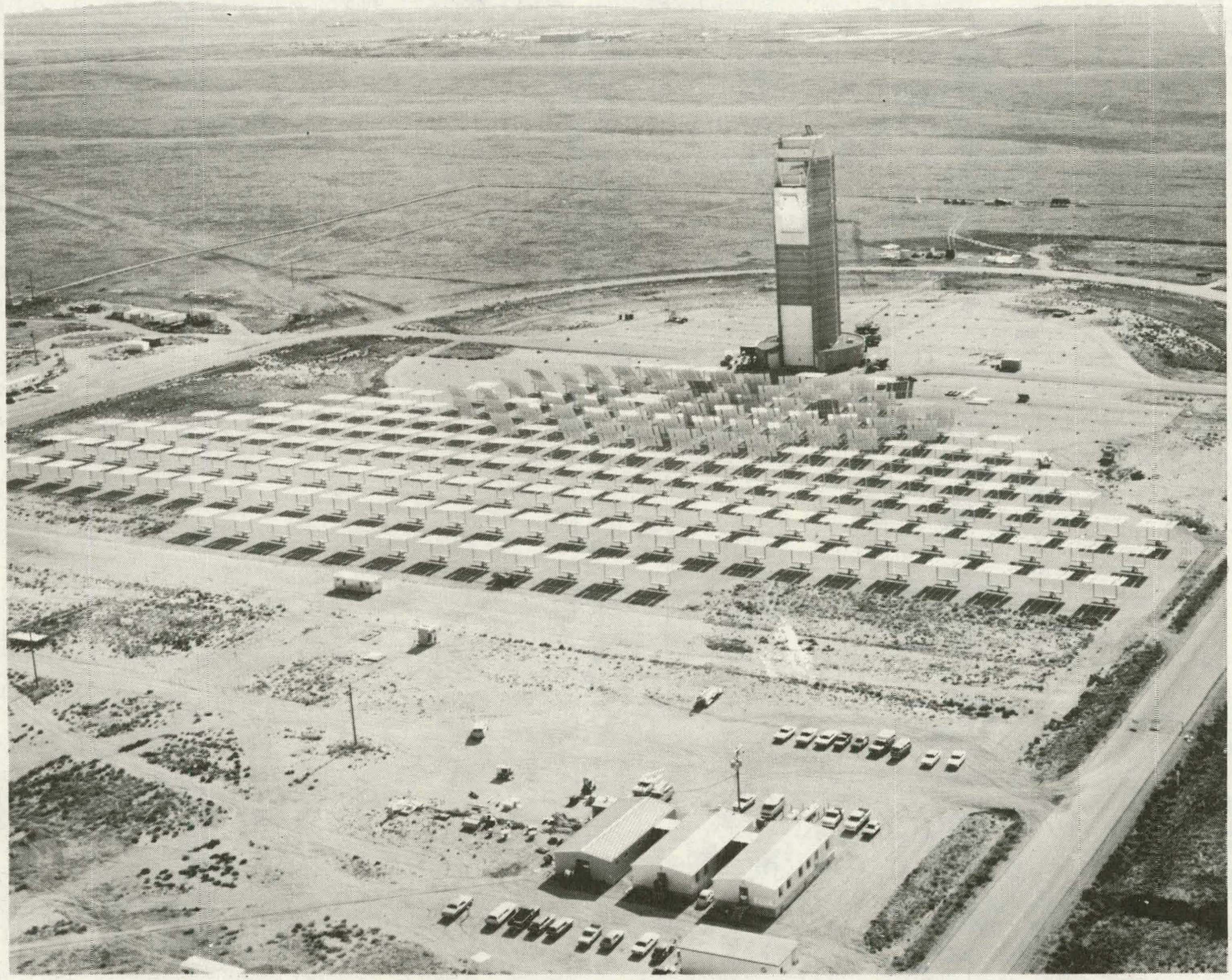

Figure 3-3. EPRI Receiver Testing of CRTF; Albuquerque, NM

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SECTION 4.0

DISTRIBUTED RECEIVERS

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

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. During 1977, 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.

4.1 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°-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 activites at the Mid-temperature Solar Systems Test Facility (MSSTF) operated by Sandia. Figure 4-1 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.

Mid-temperature trough system design and evaluation activities involving potential system suppliers have focused on three projects: the 25-hp shallow well irrigation pumping experiment at Willard, New Mexico, which began operation in mid-1977 (see Fig. 4-2); a large 150-kW deep well irrigation pumping experiment at Coolidge, Arizona (see Fig 4-3), which began operation later in 1979; and the design of a large (roughly 100,000 ft^2) trough collector array for the Ft. Hood total energy large-scale experiment. The trough system design for this military barracks application, performed by an American Technological University/Westinghouse team, was technically satisfactory but was deferred.

Another major project under way involves the use of trough collectors to supply steam for enhanced oil recovery and is a further step in the direction of demonstrating trough system capabilities in potential near-term applications. In view of restrictions on conventional alternatives, this application offers both trough and central receiver system suppliers a potentially receptive market. 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

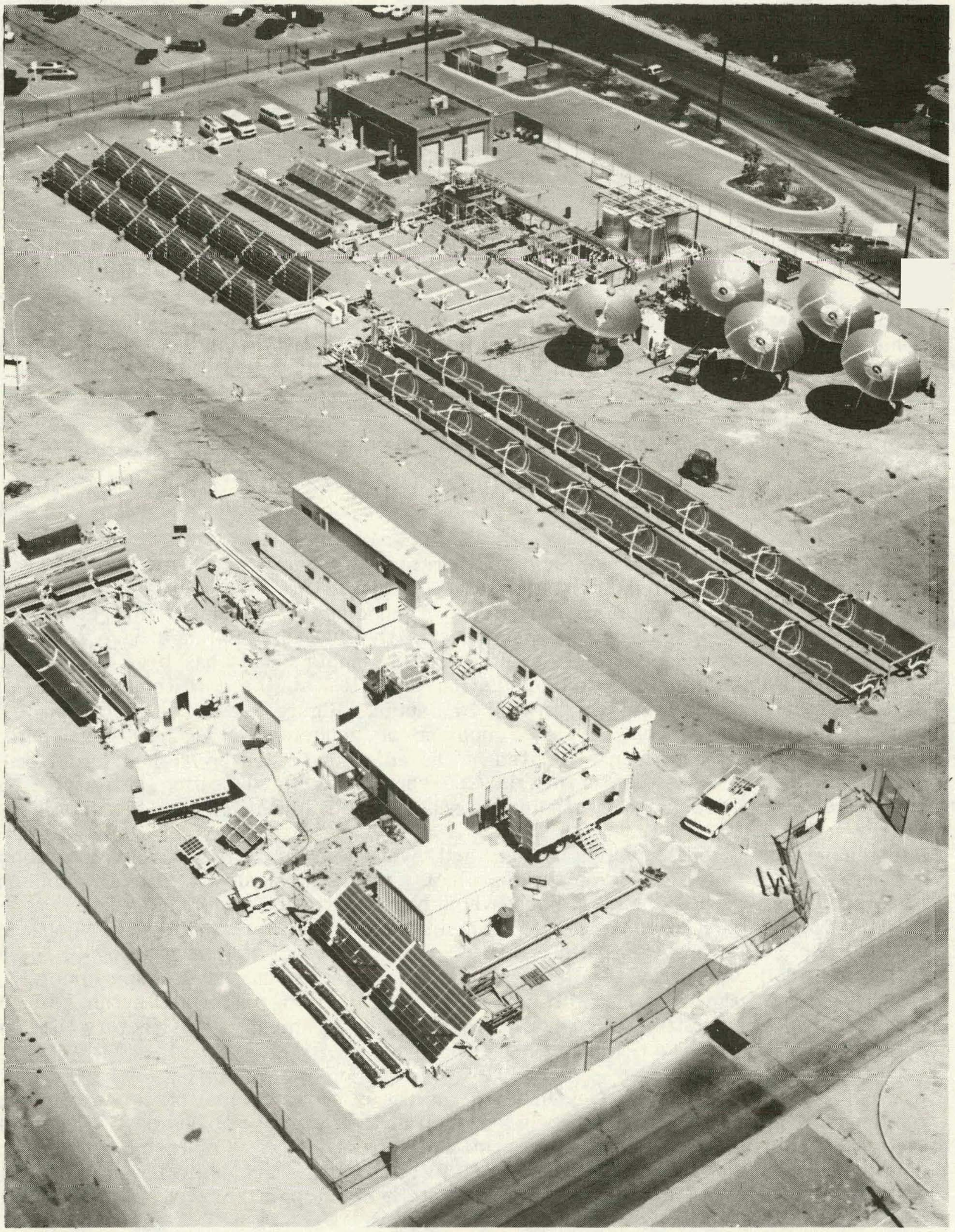

Figure 4-1. Mid- temperature Solar Systems Test Facility; Albuquerque, NM

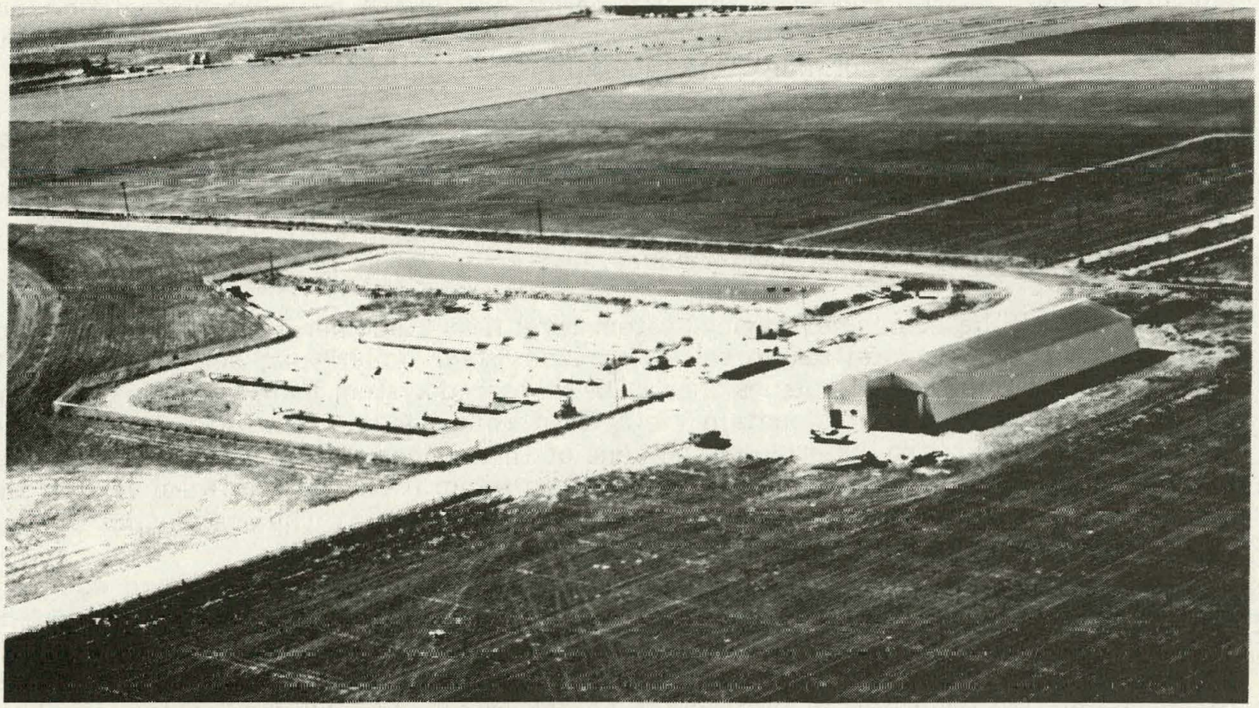

Figure 4-2. 25-hp Irrigation Pumping Experiment; Willard, NM

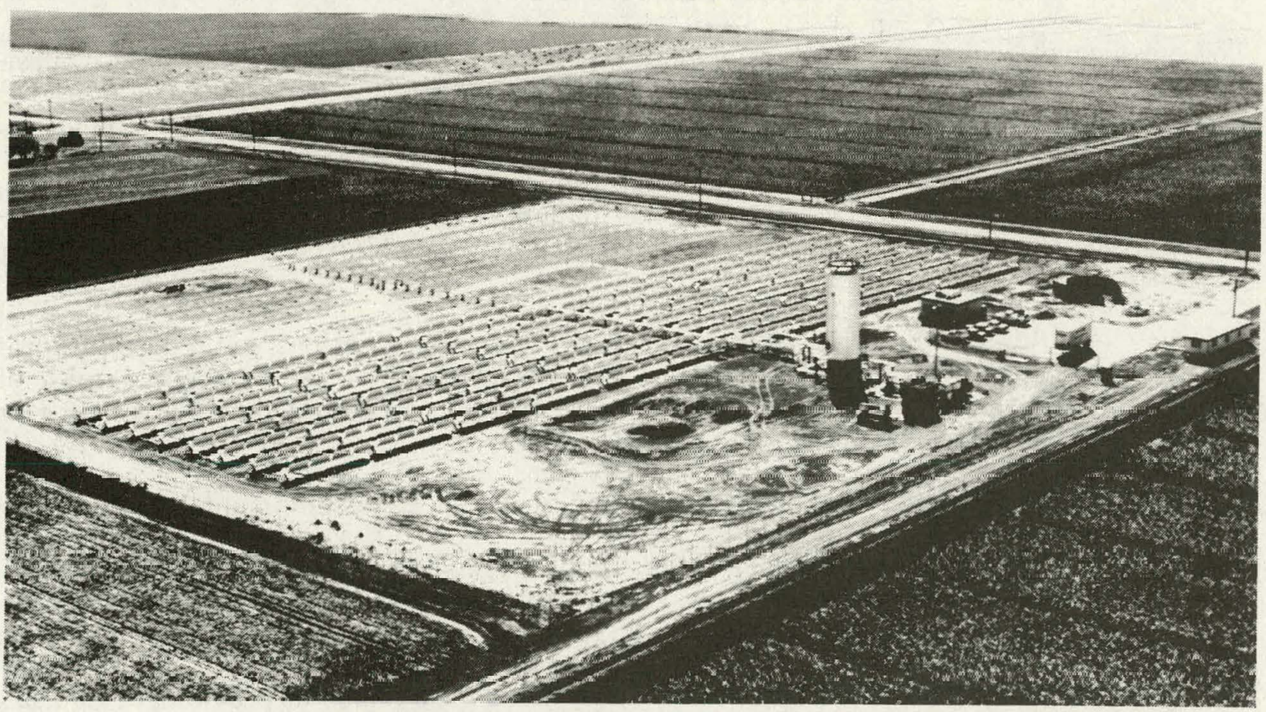

Figure 4-3. 150-kW Irrigation Pumping Experiment; Coolidge, AZ

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. 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 Program Plan. 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.

4.2 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 and fabrication of a 65-ft diameter concentrator incorporating a high temperature steam receiver module has been completed and initial testing is under way at Crosbyton.

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, Texas. The conceptual design of the system consists of ten 200-ft diameter modules, illustrated by the artist's concept in Fig. 4-4.

The bowl concept poses an interesting array of technical issues centering mostly 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 successfully tested at a smaller scale. The bowl approach was one of 10 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 1-10 MW range. The bowl, as represented by the Texas Tech/E-Systems design, was ranked by SERI low among the 10 concepts, 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.

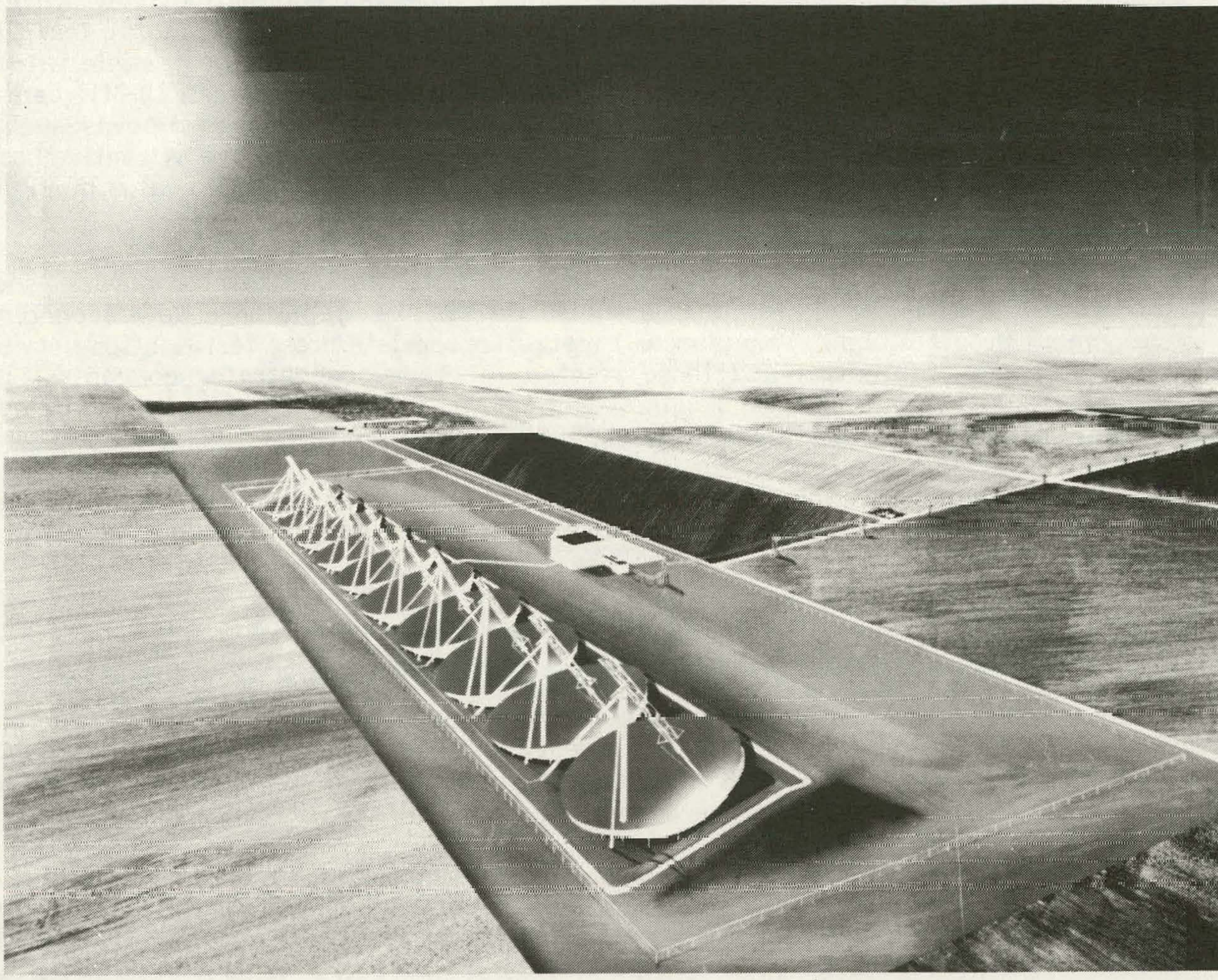

Figure 4-4. 5-MW Hemispherical Bowl Pilot Plant (Artist's Concept); Crosbyton, TX

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 $25 million. 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 approximately 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-ft 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-ft 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 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.

4.3 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, and 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 also for 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.

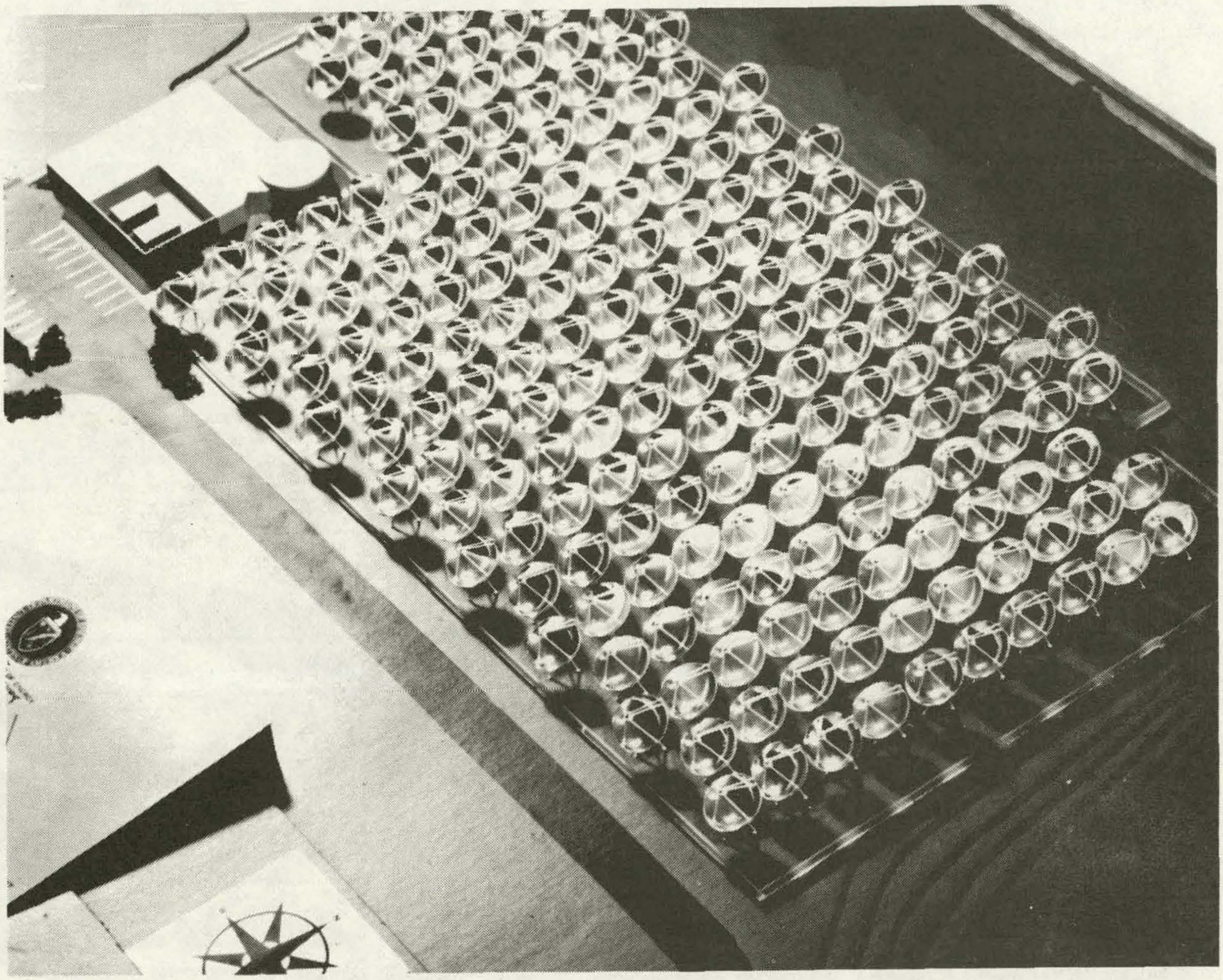

Figure 4-5. Large-Scale Total Energy Experiment (Artist's Concept); Shenandoah, GA

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, (Fig. 4-5) will begin operation in 1981. An array of 750°F dish concentrators will serve 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 (Fig. 4-6) of the dish design are undergoing validation tests at the MSSTF.

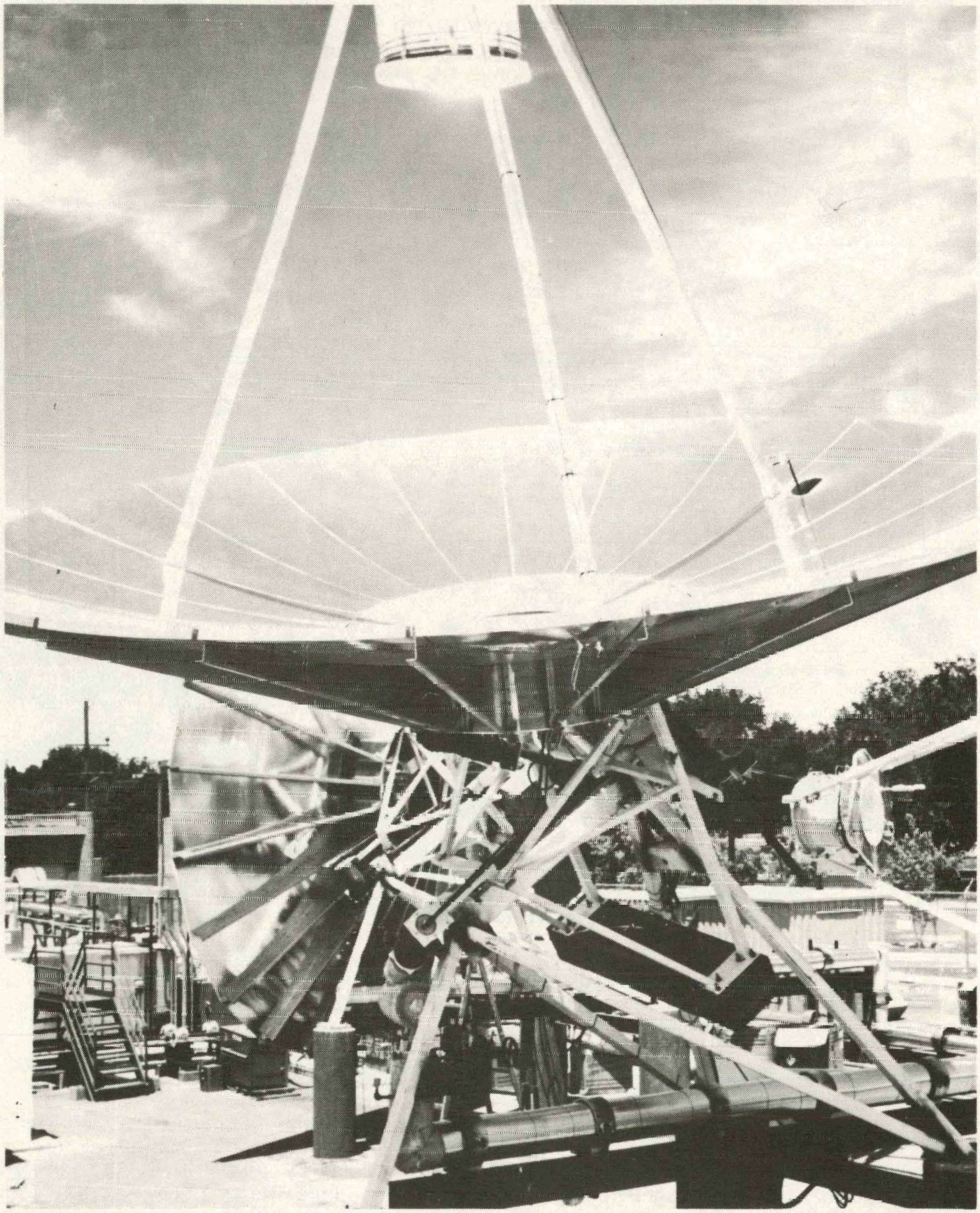

Figure 4-6. Dish concentrators for Shenandoah Project at MSSTF

A thermally-connected system under development by Ford-Aerospace has been selected for a 1-MW Small Community Experiment for which a site solicitation has been released. Industry and utility response to both the Shenandoah and Small Community projects has been enthusiastic. Over 45 small community and municipal utilities have replied to the site solicitation for the small community experiment.

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.

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 are a primary market target for photovoltaics. From a 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 engine-coupled dish modules. Each case requires different storage and/or fossil backup technology.

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 thermally connected dish systems' potential 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.

SECTION 5.0

ADVANCED TECHNOLOGY

The advanced technology program, initiated in late 1977, provides a focus for R&D paths which cut across all concentrator system concepts. These concepts 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: broadening the range of potential applications to higher temperature IPH and thermochemical fuel production, and 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 and performance thermal subsystem development, as opposed to engineering development of concentrators, allows more effective use of concentrator area.

5.1 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% or less in most of the United States. 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. DOE's Division of Energy Storage will manage the effort with a budget of approximately $5 million per year beginning in FY80.

5.2 FUELS PRODUCTION

The availability of higher temperature receiver and thermal systems will serve to expand market potential in the IPH sector. Perhaps even more significant in the long term, the high temperature capability under development may allow solar energy 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 receiver developed by Sanders Associates has been successfully tested to 2000°F at DOE's Advanced Components Test Facility (ACTF) at the Georgia Institute of Technology. Designs having potential capability above 2500°F have been selected for development. Tests at the White Sands Solar Test Facility have indicated the feasibility of coal gasification processes and oil shale retorting using a high-temperature solar heat source.

5.3 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.

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 FY80.

5.4 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. Funded within the Advanced Technology Program, the Association 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 1979 STTFUA solicitation.

Individual faculty members have already made a valuable contribution in terms of leadership and critical judgment. An expansion of university participation is planned. Future objectives include more effective use of the unique research capabilites 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.

5.5 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) project at the Solar Energy Research Institute (SERI) led by Margaret Cotton. This project 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 project 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 Solar Thermal TID project.

SERI

SECTION 6.0

ACTIVITIES IN OTHER COUNTRIES

Overseas solar thermal activities have three important dimensions:

- potential markets for U.S. products,
- potential competition for U.S. industry in these markets, and
- 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 United States 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 the project cost, about $8 million, is approximately 20% 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.

SERI

SECTION 7.0

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 1980s. IPH 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 under way. 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-ft test module under testing 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, durability, and lowering costs;
- 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 thermochemical processes.

As mass producible designs are defined and tested and production studies completed, earlier favorable cost projections are holding firm and gaining credibility. Pilot plant 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 bring about 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.

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Cost goals, systems design parameters, applications considerations, and the potential for industry involvement in solar thermal development and commercialization are described in detail. Decentralized management of R&D functions is linked to priorities and strategies of the evolving program.

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