

Bringing Solar Thermal Technology to the Marketplace



A Report To The US Congress

Submitted By

**The US Department of Energy
Assistant Secretary for
Conservation and Renewable Energy**

August, 1988

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PREFACE

The U.S. Congress, during the 1988 budget appropriation process, requested the Department of Energy to report "...its activities and plans to bring the Department's research results [on solar thermal energy systems] to the marketplace" (House Report 100-498, page 751, December 22, 1987). This is the Department's response to that request.

This report describes the significant progress already made in bringing solar thermal energy systems to the marketplace and the prospects for continued private sector market development. The report is organized in three sections. The first section, **Solar Thermal's Potential**, reviews the need for developing solar thermal technology and the payoffs resulting from its utilization. The next section, **Solar Thermal Research & Development**, discusses the solid technology base that has been established and the current emphasis of R&D efforts. In the third section, **Progress in Commercial Applications**, success in bringing first-generation solar thermal systems to the marketplace is reviewed and processes and prospects for continued market development are outlined.

The development of this report relied heavily on input and critique from both current and potential users of solar thermal energy systems and companies involved in solar thermal technology research and product development.

EXECUTIVE SUMMARY

THE NEED AND SOLAR THERMAL'S POTENTIAL

The nation faces many difficult challenges in energy supply and use. The many vital issues include energy security, energy cost, international balance-of-trade, international competitiveness, and environmental quality. Energy security requires maintaining assured access to sufficient energy resources, and doing so at a cost that does not disrupt our standard of living. It is essential from the perspectives of national defense, the trade deficit, and political stability that we limit our dependence on foreign energy supplies. Growing pervasive problems with atmospheric pollution, water resources, acid rain, and the greenhouse effect may ultimately limit the burning of fossil fuels. Most experts agree that, unlike in the past when we relied on a few primary sources of energy such as coal and oil, a mixture of energy alternatives will have to be developed for the future.

Solar thermal technology has a number of attractive attributes that make it a very desirable energy supply option: it is a strategically secure energy source; it has low environmental impact; and it has short construction times and can be built in modules to respond to demand growth. As part of a balanced national energy strategy, the wide spread implementation of solar thermal energy systems has the potential to increase our domestic energy supplies, to reduce our dependence on imported oil, and to help U.S. industry respond to increasing international competition for domestic and overseas markets for solar energy systems.

SOLAR THERMAL TECHNOLOGY AND ITS APPLICATIONS

Concentrated sunlight is a very versatile and high-quality form of energy. Therefore, solar thermal technology has a broad spectrum of applications, which include industrial and commercial uses of process heat, electrical power generation, hazardous waste destruction, and a variety of other advanced applications that take advantage of the unique attributes of highly concentrated sunlight. Solar thermal systems use concentrating collectors to focus sunlight so that high temperatures can be achieved to produce high-quality energy. Three types of concentrating collector systems are being developed in the DOE's Solar Thermal Technologies Program. These are parabolic troughs, which focus at low concentration ratios and are used for mid-temperature applications, and parabolic dishes and central receivers, which are capable of

achieving high concentration ratios and therefore very high temperatures.

THE DEVELOPING MARKETPLACE

Efforts to bring solar thermal systems to the marketplace are already bringing measurable results (see inset titled **Commercial Solar Thermal Systems**). Building on the wealth of system experience developed in the DOE Program, several companies have made commercial sales of parabolic trough industrial process heat systems, and these systems are operating well. The present low price of oil and natural gas has limited the penetration of this technology into the process heat market. However, Luz International has installed more than 130 megawatts of electrical power generation using similar parabolic trough technology. Luz has scheduled an additional 500 megawatts for introduction in the near future. Today, these parabolic trough systems generate electricity for 10-12 cents per kilowatt-hour and have the potential for even lower cost. The LaJet Energy Company has also installed a 5-megawatt, investor-owned power plant, SOLARPLANT 1, that uses 700 parabolic dishes to generate steam for a centrally located turbine-generator.

An assessment of the developmental status of the various solar thermal technologies, coupled with an examination of the business plans and projections of industry and users, leads to the conclusion that *significant marketplace opportunities exist in both the near and long terms*. Two applications with high early market potential are electric power generation and hazardous waste destruction. The aggregate size of such markets in the southwestern U.S. alone, projected to be about 35,000 megawatts in the next decade, is huge compared to a sustainable production volume for the U.S. solar thermal industry. Development of export markets for solar thermal systems can also contribute significantly to the market base.

Applications judged to have the highest potential for bringing additional solar thermal technology to the domestic and export marketplace within a 5-year timeframe are

- **trough and dish systems for electric power generation in plants similar to Luz's SEGS Plants and LaJet's SOLARPLANT 1 with centrally located engine/generators, and;**
- **solar destruction of hazardous wastes through the combination of high-temperature and photo-enhanced chemical reactions.**

In 5-7 years, solar thermal systems based on advanced components with higher performance and lower cost should find substantially expanded domestic and export market opportunities. Examples of these potential applications are (also see inset titled **The Promise of a Developing Marketplace**)

- **central receiver electric power plants using low-cost glass-metal or stretched membrane heliostats and an advanced molten-salt receiver, and;**
- **dish-electric systems, which utilize low-cost membrane concentrators and advanced focal-mounted engines, for remote and grid-connected markets.**

Advanced applications based on the unique properties of the concentrated solar spectrum, as fuels and chemicals production and materials treatment, are likely to be important additional markets within 10 years.

STRATEGY FOR MARKETPLACE DEVELOPMENT

The DOE's strategy for bringing results of solar thermal research to the marketplace is centered on the development of improved cost effectiveness and reliability of solar thermal components and the development of additional early markets with high strategic or economic value by U.S. industry. This balanced, two-part approach of R&D coupled with market development will introduce essential technological improvements while allowing industry to acquire the production experience base to further lower the cost. Implementation of this strategy relies on a core program of enabling high-risk research to identify and prove new concepts and processes, technology development to translate research into useful prototypical hardware, interactive industry and user technical assistance efforts, and joint venture projects. These four key program elements are outlined below.

ENABLING RESEARCH

Research efforts in the DOE Solar Thermal Program are developing the foundations necessary for enablement of a viable solar thermal technology. These research efforts are focused on concepts, processes, and materials for a broad range of applications and on the identification and proof-of-concept of advanced applications for highly concentrated solar energy, as follows:

- **research on optical materials and advanced optical techniques for high-performance, lower cost solar concentrators;**

- **research on high-temperature materials and concepts receivers that efficiently handle high solar flux;**
- **research on materials, processes, and components for the solar destruction of hazardous wastes; and**
- **research to apply the unique attributes of concentrated flux to fuels and chemicals production and materials processing.**

TECHNOLOGY DEVELOPMENT

Technology development efforts translate research results into essential prototypical hardware that enables industry to approach a broad range of market opportunities with proven, high-quality, cost-effective, and reliable hardware. DOE/industry cost-sharing of the development of key components to reduce risk, enhance U.S. industry competitiveness, and to verify performance, manufacturability and reliability is sought as a means of leveraging R&D funds. Current efforts are on innovative approaches to reducing cost and improving performance of key solar components as follows:

- **development of low-cost, light weight stretched membrane heliostats and parabolic dish collectors;**
- **development and testing of advanced molten-salt receivers and transport components for central receiver plants;**
- **development of advanced, ultra-high-flux sodium-reflux receivers for dish systems;**
- **development of reliable, high-performance, low maintenance focal-mounted engines for dish-electric systems; and**
- **development and testing of advanced falling-salt-film, direct-absorption receivers for central receiver plants.**

TECHNICAL ASSISTANCE INITIATIVES

Successfully bringing solar thermal technology to the marketplace depends on strong interaction between enabling research and technology development efforts and industrial initiatives to identify and develop commercial markets. Industry builds on the R&D base through application projects and provides feedback to identify supporting technical activities essential to initial market penetration. Specific mechanisms that facilitate this process are

- **provision of technical assistance to suppliers and users of solar thermal technology;**

- **exploitation of export and domestic market opportunities through the Committee on Renewable Energy Commerce and Trade (CORECT); and**
- **development of technical information products to assist industry market development efforts by increasing awareness of solar thermal technology and its appropriate applications.**

Through activities of this nature, industry can better pursue near-term, high-value markets that expand its production and experience base.

JOINT VENTURE PROJECTS

Introduction of new energy technology into the marketplace could take the form of joint venture projects that spread any risk among a number of participants. Such projects allow the supplier, user, and investment communities to gain essential experience with the design, performance, operation, economics, and financial requirements of developing technology. Limited, carefully structured federal program participation in such solar thermal activities encourages private sector investment and provides beneficial linkage to the R&D efforts.

In summary, successful penetration of a variety of early markets for thermal technology will help ensure the vitality of an important renewable energy option within our national energy strategy. This requires coordinated government and private sector efforts to bring the emerging solar thermal technology into the marketplace. The entry of industry into these markets, which represent applications of strategic or premium economic value, can build on current technology, reduce manufacturing costs, and help U.S. industry compete in the international marketplace.

SOLAR THERMAL'S POTENTIAL

THE NEED FOR SOLAR THERMAL ENERGY

Our nation faces many difficulties and challenges. One of the most pervasive and important challenges is the need to achieve energy security [Ref 1]. This not only means that we must strive to gain assured access to sufficient energy resources, but we must do so in a manner that fosters our national security, maintains or improves our economy, enhances our international competitiveness, and maintains our environmental quality.

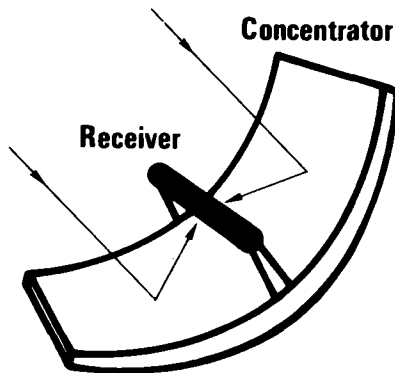
Solar thermal energy technology (See inset titled **The Basic Concepts of Solar Thermal Technology**) is an integral part of the DOE's strategy to help our nation achieve energy security. As part of the national solar program, solar thermal energy technologies increase our domestic energy supply options, enhance our superiority in energy and spinoff technologies, reduce our dependence upon imported energy sources, and open new domestic and overseas markets.

The current use of solar energy in all applications is far less than it could be. Research and development conducted by DOE, industry, and utilities over the past decade have developed new technologies critical to the viability of solar thermal systems and have reduced technical and financial risks. First-generation solar thermal systems have enjoyed limited but encouraging success, proving the basic utility and functionality of the technology for generating heat and electricity. However, low fuel costs, changes in the availability of federal and state tax incentives, and other market factors have delayed the time when new energy technologies will become economically competitive, except in a few high-value markets. In addition, the Public Utility Regulatory Policy Act (PURPA) has encouraged third-party suppliers to meet much of the demand for new electrical generating capacity using fossil fuels in cogeneration systems. The availability of power from third-party suppliers, combined with conservation and a lower-than-anticipated rate of growth in demand for electrical power, has left many utilities with excess generating capacity.

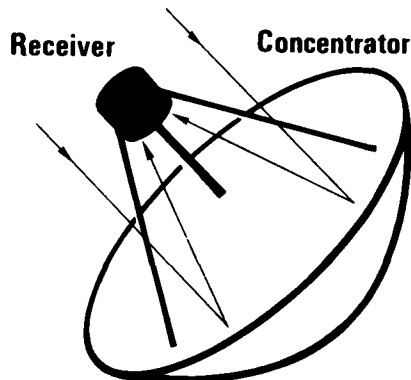
Although current oil supplies are adequate and prices are low, experts agree that this situation should change in the future. In

The Basic Concepts of Solar Thermal Technology

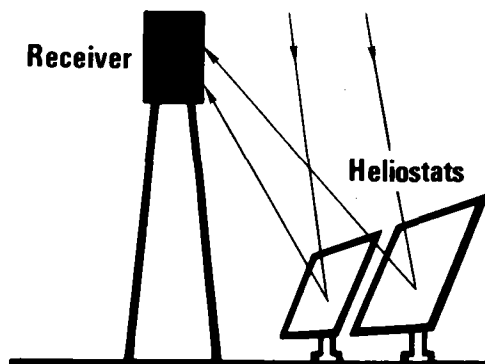
Solar thermal systems convert sunlight to useful energy forms by **concentrating** the sun's radiation so that high temperatures can be attained, and then **converting** this energy into process heat, electricity, or products such as fuels and chemicals. All concentrating solar collectors must track the sun and all use reflectors or lenses to intercept and redirect the sun's rays. Over the past decade three main types of concentrating collectors have evolved: low-concentration **parabolic troughs** and high-concentration **parabolic dishes** and **central receivers**. High concentration allows achievement of much higher temperatures which makes electrical generation more efficient and, because of the unique nature of concentrated sunlight, allows initiation of photolytic processes.



Trough systems. Typical and most mature among low-concentration concepts are trough systems, which use parabolic reflectors in a trough configuration. Troughs concentrate the sun up to 100 times onto a fluid-filled receiver tube positioned along the line of focus in the trough. Heat can be produced efficiently up to 400°C (750°F) and is used as heat or to generate electricity. Troughs are modular, and many of them can be grouped together to produce more heat or power. As a result of a concentrated R&D effort in the early years of the DOE solar thermal program, this is the most mature of the solar thermal collector technologies. Critical technology developed and applied to today's modern trough systems includes: silvered polymer reflective films which cover the trough's primary collection surface; selective absorber coatings for receiver tubes that have a high absorptance for solar radiation but a low emittance for thermal radiation loss; and economical sun-seeking tracking sensors and controllers that use state-of-art optoelectronic devices and microelectronics. Industry is adopting and successfully implementing trough systems in the marketplace. Over 15 million square feet of parabolic trough collectors have been manufactured and sold commercially in the United States.



Dish systems use parabolic reflectors in the shape of a dish to focus the sun's rays onto a receiver mounted above the dish at its focal point. The solar energy heats a fluid circulating through the receiver which is pumped elsewhere for a variety of uses including electrical generation (the dish-central-engine concept), or a small engine/generator is mounted at the focal point of the dish (the dish-electric concept). Operating at about 800°C a single dish module generates up to 50 kilowatts of electric power. Like trough systems, many dishes can be grouped together to produce more power. Dishes achieve the highest performance of all concentrator types in terms of annual collected energy and peak solar concentration. Solar flux as high as 30,000 suns and temperatures up to 3000°C (5400°F) have been achieved with dishes. This intense heat and solar flux makes them potentially suitable for destroying toxic wastes, making chemicals, producing fuels, and creating exotic materials. Dish technology is not as mature as trough technology and requires continued R&D on the concentrator, receiver and conversion processes. The concept of stretched-membrane dish concentrators, currently being researched, holds great promise for reduced cost.



Central receiver systems use heliostats (highly reflective mirrors) that track the sun and reflect it to a central receiver atop a tower. The sun heats a fluid in the receiver typically to temperatures up to 650°C (1200°F). The heated fluid drives a turbine to produce electric power. This concept has been proven at the 10-Megawatt Solar One system installed near Barstow, California, which used a pressurized water/steam receiver. Through their experience with this system, researchers are designing better and cheaper heliostats (such as the stretched-membrane heliostat), better receivers (molten salt and falling-film direct absorption types) and computerized controls that can run the solar thermal plant more cost effectively. Further, this concept can also achieve temperatures up to 2500°C (4500°F) with very high concentrations for non electric applications.

1987, U.S. crude oil production declined to the lowest level in a decade, while imports grew at the fastest rate since 1980. Today, almost 40 percent of the oil used in the U.S. is imported, further exacerbating our trade deficit. In addition to the decline in proven U.S. reserves, the number of new wells drilled each year has dropped over 50 percent since 1985, and the cost of developing new reserves continues to increase.

Solar thermal systems not only have uses that are viable today, but they contain great promise for tomorrow. Future applications of solar thermal systems extend beyond heat and electrical generation. Because of their capability for high heating rates and because of special reactions possible with concentrated sunlight, solar thermal systems have many other unique applications. They may be used, for example, to efficiently and effectively destroy hazardous wastes close to their source and thus to mitigate environmental problems. Solar thermal systems may also be used to produce transportation fuels and to make industrial chemicals and space-age alloys.

THE ISSUE OF INTERNATIONAL COMPETITIVENESS

The advantages of solar thermal energy systems are not being lost on our international competitors as evidenced by a European consortium investing in the technology. Likewise, in response to energy supply uncertainty and concerns, countries such as India, the USSR, Italy, Israel, Spain, Switzerland, West Germany, Japan, and China, are increasing their investments in solar thermal research. These actions are a serious threat to the United States leadership in solar thermal technology developed over the past decade.

Foreign interests in solar thermal technology do not stem from concerns over internal energy supply alone. These countries want to gain the technological edge to export technology in evolving international markets. Italy has recently made an agreement to obtain help from Israel on solar thermal and other renewable technologies; Germany and Spain have agreed to cooperate in developing components and testing them at the solar facility in Spain; and India has shown interest in obtaining solar electric systems whose components are fabricated in Germany and Israel. These are only some examples of the developing, serious international competition in renewable energy technologies.

THE POTENTIAL OF SOLAR THERMAL SYSTEMS

The uncertainty of today's energy environment makes predicting the future of all energy supply options tremendously difficult and imprecise. However, a number of studies have attempted to project the potential of new energy technologies in a comprehensive manner, and they provide insight into the timeframe and extent of the potential impact of solar thermal systems. The National Energy Policy Plan projects that solar thermal will penetrate the market to the extent of 1 to 2 quads per year by the year 2010 [Ref 2]. (A quad, or one quadrillion Btu's, is a measure of energy equivalent to 172 million barrels of oil, or to nearly 100 billion kilowatt-hours of electricity. The United States currently consumes about 80 quads of energy per year.) Other studies, which view market potential in terms of the maximum amount of energy that a technology can economically supply in a given year, suggest that solar thermal will have an energy contribution potential of nearly 10 quads a year by the year 2010 [Ref 3]. These studies have considered only domestic markets and not the developing international marketplace.

In achieving a projected contribution of a quad or more per year, solar thermal technology has the potential for creating multi-billion dollar markets, both domestically and abroad, making the U.S. more competitive internationally. It has the potential to displace enormous amounts of liquid fuels that must otherwise be imported. It has the potential to provide us with a cleaner environment than we would otherwise attain. In addition to its potential for electricity supply, it has the potential to supply even more quads of energy per year in heat and fuel production. It also has the potential to produce chemicals, metal alloys, and other high-value materials, such as altered carbon fibers and ceramics with unique properties.

PROGRESS TOWARD ACHIEVING THIS POTENTIAL

A decade of research and development has brought solar thermal systems to a point where they have been proven useful for process heat and for generating electricity. Such systems are being marketed in regions where the competitive cost of energy is high. Moreover, this important experience base with first-generation technology has identified where and how significant improvements to the technology can be made. This experience also demonstrates important marketplace attributes of solar thermal technology. Because they are modular, solar thermal systems can gener

electricity economically at power levels that range from tens of kilowatts up to and exceeding several hundred megawatts. Modularity has the additional advantage of short construction times and incremental investments. Solar thermal generating plants operating in utility grids have also demonstrated their ability to provide a firm capacity factor and high availability.

Today, solar thermal energy can provide electricity at utility-scale power levels. Already there is over 140 megawatts of installed generating capacity using solar thermal energy in the southwestern United States. Solar energy is ideally suited to this region because of the high percentage of sunny days, the relatively high cost of electricity, and the need for non-polluting energy sources. In addition, the modularity, size versatility, and short lead time of a solar power plant mesh well with the responsive planning environment desired by utilities to respond to demand growth. This capacity is planned to grow to over 500 megawatts in the next few years. These power plants, built by Luz International and LaJet Energy Company, are 100% privately financed, and sell power to utilities under long-term power purchase agreements. When completed, they will represent an investment of over 1 billion dollars. This commercialization of first-generation solar thermal technology is possible because of a favorable financial environment and because of the significant progress made in increasing efficiency and reducing the cost of solar thermal systems.

THE MANY USES FOR SOLAR THERMAL TECHNOLOGY

ELECTRIC POWER GENERATION. The demand for electricity in the United States is closely coupled to economic growth. In the southwestern United States, the demand for electricity is growing at a steady rate of 2.5% annually. This and other factors will create a need for an additional 33,000 megawatts of installed capacity in the Southwest alone by 1995, enough electricity to serve about 30 million households [Refs 4-6].

The Office of Technology Assessment (OTA) points out that by 1995 a quarter of our coal-fired power plants and nearly half of our oil- and gas-fired steam plants will be over 30 years old [Ref 7]. These aging units could result in a shortfall of 100,000 megawatts or more by the year 2000.

Solar thermal systems are well suited to help us meet our electric power generation needs. They function well in utility grids, providing a good capacity factor and availability. They are modular; plants using them will require short lead times and they can be built incrementally to fit demand growth needs. They are versatile; they can be used in dispersed or centralized locations. And they are becoming cost effective; today parabolic trough systems generate electricity for as little as 10-12¢ per kilowatt-hour and have the potential for even lower cost. Central receiver and dish technologies, which have an even greater potential for efficiently generating electricity, are expected to ultimately produce electricity at 5-8¢ per kilowatt-hour.

PROCESS HEAT. The greatest consumption of energy in our society comes from the industrial sector. Much of this energy is consumed to produce mid-temperature (200-600°F) process heat. Solar thermal technology is ideally suited to process heat applications. The technology base for process heat applications is largely developed and has been demonstrated, through the DOE MISR (Modular Industrial Solar Retrofit) program, to effectively integrate solar augmentation into existing process heat plants. Although a few firms now market commercial products (mostly parabolic troughs), the recent low price of oil and natural gas, along with the expiration of tax credits for solar, has substantially reduced the domestic market. Opportunities may exist in export markets, and the U.S. government and industry are aggressively pursuing these possibilities through the Committee On Renewable Energy Commerce and Trade (CORECT).

ADVANCED APPLICATIONS. Beyond the use of solar thermal technology for generating electricity and process heat, there are advanced applications that address critical national problems and offer exciting potential. Several of them are described below.

Hazardous Waste Destruction. The United States is now producing 290 million tons of hazardous wastes annually. Of this amount, only 4 million tons are being destroyed in monitored incineration processes [Ref 8]. To meet destruction levels required by the Environmental Protection Agency, many toxic solvents, pesticides, and other chemicals must be incinerated with tight controls at temperatures as high as 1200°C (2200°F). There is a severe shortage of incineration facilities licensed for hazardous

waste destruction, and the situation will worsen as hazardous wastes accumulate and as standards become more stringent.

Recent laboratory results show that solar thermal systems can help our nation destroy its hazardous wastes. The advantages of solar destruction include reduction of incomplete combustion products, the ability to incinerate in a non-oxidizing environment under better control of thermal input conditions, and on-site destruction, which eliminates the need for accumulation and transportation of hazardous wastes to disposal sites. Examples of particular interest to solar destruction are accumulated concentrated industrial toxic chemicals, chloroflourocarbons (CFSs), and accumulated containerized organic solvents.

Materials and Chemicals Processing. Using high-energy photons, rapid heating, and very high temperatures, solar thermal systems produce a wide range of unique process conditions. Laboratory research has already shown that photoenhanced catalytic reactions are created by highly concentrated solar energy at the surface of catalysts. Possibilities for tailoring reactions are now being investigated to explore their potential to produce valuable chemicals, such as octane enhancers in liquid fuels. The rapid heating capabilities of concentrated sunlight may also provide an effective means for liquefying coal. Such a process would reduce pollution and waste problems while saving considerable amounts of fossil energy. The concentrated solar spectrum also shows promise for advanced surface processing techniques to produce materials such as carbon composites and ceramics that could replace some strategic materials.

Research in the DOE Solar Thermal Program is currently focused on such advanced applications of highly concentrated solar energy. It is aimed at identifying and understanding fundamental processes along with proof-of-concept experiments that will guide the way to expanded use of solar thermal technology.

SOLAR THERMAL RESEARCH & DEVELOPMENT

In response to the energy crisis of the early 1970s, the National Science Foundation established several solar thermal research and technology development programs. These programs were consolidated in 1975 and expanded by the Energy Research and Development Administration (now the Department of Energy). Under the leadership of DOE, the Solar Thermal Program has been carried forward by industry, users, universities, and national laboratories.

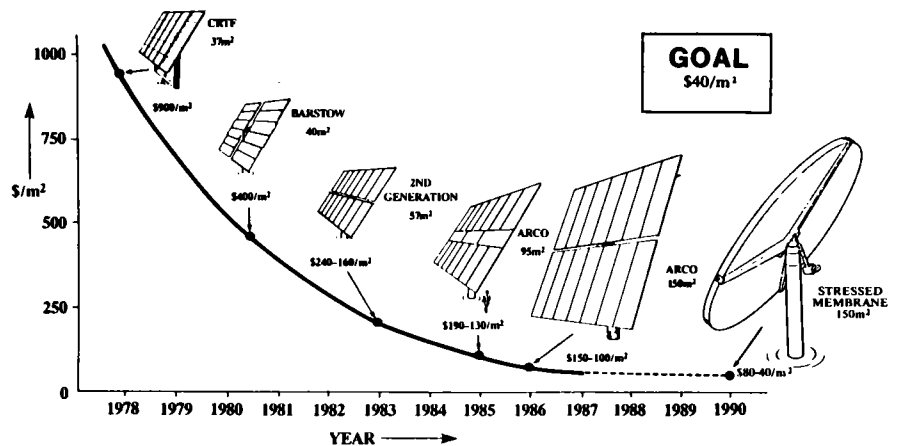
The DOE Solar Thermal Program has historically focused on the R&D of solar-specific components and processes [Ref 9]. Components have been developed, integrated into systems, analyzed, and their performance verified through small-scale tests. Once component performance was established, prototypes were assembled into systems and evaluated to gain experience and to identify and resolve problems at the system level. Each step in this process further refined the technology and provided feedback for continued R&D improvements. Cooperative efforts between DOE, industry, and utilities occurred at each step in this development process.

A SOLID BASE OF ACCOMPLISHMENTS

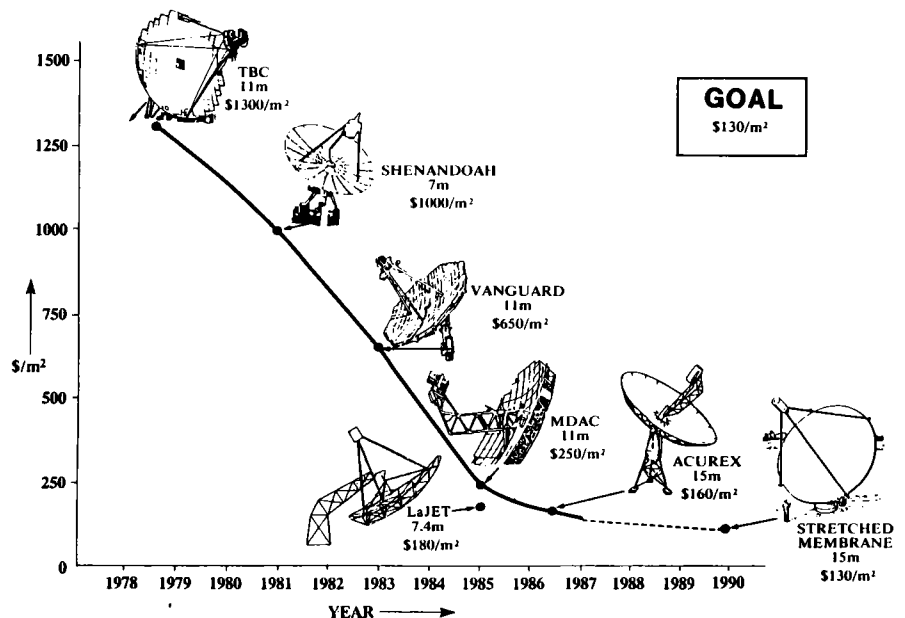
Component R&D. DOE activities have been directed at developing new materials, processes and components for solar thermal systems. Some of the materials and processes that have been incorporated into commercial components include absorber coatings for receiver tubes, durable glass and aluminum mirrors, and efficient thermal storage systems. These early R&D results improved the performance of first generation concentrators, receivers, tracking and drive controls, and heat engines. The reduced cost, improved performance and reliability of these components is a measure of the success of R&D efforts. For example, commercial heliostats of today using glass reflectors are four times as large as those of 10 years ago and, over the same time span, costs have been reduced by nearly a factor of 5. Continuing R&D is now leading towards the development of lightweight film reflectors with the promise to further reduce concentrator costs by another factor of two.

Receivers for solar thermal systems have also evolved during past decade. Initially small-scale field experiments were needed to investigate the feasibility of using tube receivers to produce steam. In the early 1980s a scaled-up water/steam receiver was deployed in the 10-megawatt Solar One Pilot Plant, a systems experiment developed by DOE in conjunction with Southern California Edison Utility Company. Today's R&D efforts are aimed at further reducing receiver costs through the use of advanced designs and molten salts as the heat transfer fluid.

*Progress In
Heliostat R&D*



*Progress In Dish
Collector R&D*



Similarly, the performance and cost of components for parabolic dish and trough systems have been improved dramatically through DOE's efforts. These technologies have taken advantage of new receiver coatings, accurately shaped glass reflectors, rotary joints for fluid transport, and engine development. In fact, these efforts have been so successful in trough technology that industry is now refining and commercializing this technology without further assistance from DOE.

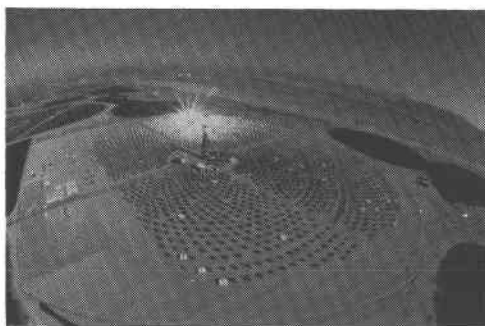
Systems Experiments. Before component improvements could be commercialized, it was necessary to integrate them into systems that could be operated to identify and solve system-level engineering problems. DOE, industry, and users recognized that this experience was an essential element in the process of developing commercial solar thermal systems. Cost-shared system experiments have been a highlight of the Solar Thermal Program and in many cases have led to successful commercial ventures (see inset titled **A Wealth of Solar Thermal Systems Experience**). These experiments provide an extensive performance and reliability data base as well as valuable operating experience and feedback to R&D.

The results from DOE's R&D and systems experiments have been aggressively transferred to the marketplace. Initial commercial systems capable of delivering electricity for 30 cents or more per kWh entered the marketplace because of the availability of federal and state tax incentives. However, subsequent improvements in performance and cost have resulted in systems that can produce electricity for as little as 10-12¢ per kWh in the southwestern U.S. As additional improvements are made, it is expected that these costs will be further reduced and that subsequent generations of solar thermal systems will become cost effective in an even wider range of applications.

ENABLING RESEARCH

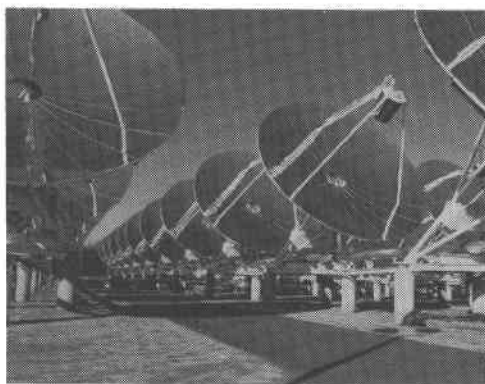
Research efforts in the DOE Solar Thermal Program are developing the basic foundations necessary for enablement of a viable solar thermal technology. These core, high-risk research efforts are focused on concepts, processes, and materials for a broad range of applications and on the identification and proof-of-concept of advanced applications for highly concentrated solar energy.

A Wealth of Solar Thermal Systems Experience



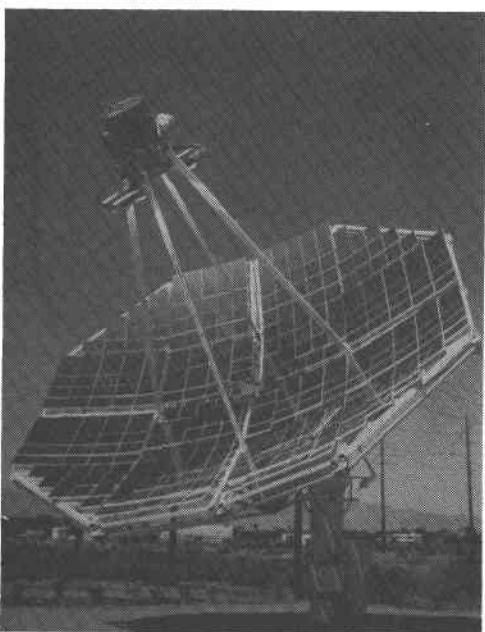
Solar One. The world's largest central receiver plant is the 10 MW Solar Pilot Plant operated by the Southern California Edison (SCE) Company near Barstow, California. In five years of operation, the cost shared project has provided valuable data on the operation, reliability, and maintenance of a central receiver power plant. Based on this experience, design improvements were identified that led to current central receiver designs that are substantially more efficient than Solar One. SCE continues to operate the plant in a semi-commercial phase, and performance has continued to improve.

The Molten Salt Electric Experiment. MSEE was the first test of a high-performance, central receiver system that uses molten salt as the heat transfer fluid. Private industry, funded by DOE and the Electric Power Research Institute, designed and fabricated all major system components. Tests, conducted at the DOE Solar Thermal Test Facility, demonstrated that efficient thermal storage could be used to generate power when solar energy was not available. MSEE provided industry with valuable hands-on experience in operating a central receiver power plant and led directly to today's improved system designs.



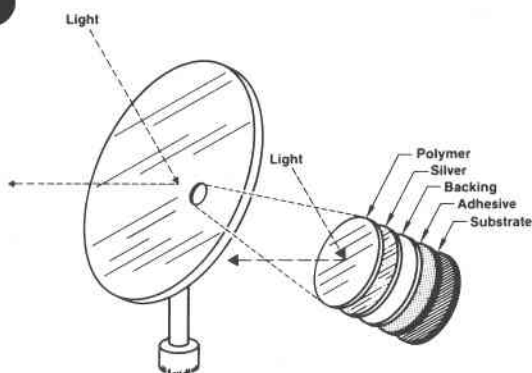
Solar Total Energy Project. The Shenandoah Project, located south of Atlanta, Georgia, uses 114 parabolic dish collectors to produce electricity, process steam, and air conditioning for a nearby factory building. Shenandoah was funded through a cooperative agreement between the DOE and the Georgia Power Company, which assumed project ownership and has continued to operate the system. Georgia Power has continued to upgrade the system to increase energy production and reduced operation and maintenance costs.

The Vanguard Project. The combination of a parabolic dish collector and a Stirling engine has long been viewed as a candidate for the highest efficiency solar power plant. The Vanguard Project, a 25 kW_e dish-Stirling system, became operational in 1984 at an SCE substation in Rancho Mirage, California. The project, was funded by a cooperative agreement between the DOE and the Advanco Corporation. Vanguard holds the world's net solar-to-electric efficiency record of 29.4%. During one continuous 14 day period, it demonstrated a sustained solar-to-electric conversion efficiency of 25%.



Modular Industrial Solar Retrofit Project. The Modular Industrial Solar Retrofit (MISR) Project was designed to provide industry with near-commercial scale experience in generating process steam. Five contractors designed, built, and installed systems using state-of-the-art silvered glass and polymer film reflectors, evacuated tube receivers, advanced flex hoses and rotary joints, and low-cost lightweight concentrator structures. MISR bettered DOE's long-term trough peak thermal efficiency goal of 65% (solar-energy-to-thermal output) by three percentage points, suggesting that the program's annual thermal efficiency goal of 56% is achievable.

Solar Irrigation Projects. Some of the earliest system experiments used trough technology and heat engines to produce shaft power for irrigation systems. The largest of these, the 150 kW_e Coolidge Solar Irrigation Project, was funded through a cooperative agreement between DOE and the State of Arizona. The operation of the plant demonstrated a "hands-off" automated control system and established an outstanding reliability record, operating 97% of the time. Coolidge was also the first large-scale application of a polymer reflective film.



*Silvered Polymer
Film For Membrane
Heliostats*

Materials Research. The development of reflective polymer films and sol-gel glass front-surface mirrors will reduce the cost of solar collectors while maintaining the high-performance levels achieved by glass reflectors. The production of light weight, abrasion-resistant, reflective surfaces allows industry to design collectors that are larger and yet lower in cost. In addition to work on optical materials, research and development of improved high-temperature materials will continue to reduce the cost of solar receivers and improve their thermal performance.

Destruction of Hazardous Waste. Laboratory experiments using solar simulators have shown that photon energy can initiate chemical reactions to break down wastes more efficiently and at lower temperatures than standard techniques. Recent tests conducted in a solar furnace, using a directly illuminated catalyst loaded into a porous ceramic matrix, proved the feasibility of obtaining temperatures in excess of 1200°C at the catalyst's surface. A series of experiments to measure the destruction efficiency of numerous chemicals in the presence of various catalysts and other reactants is now underway.

Materials Processing. Solar thermal systems can create high heating rates and high power density for materials processing. Such systems are more efficient and can be applied to larger surfaces than conventional laser heating techniques. Laboratory-scale experiments have been performed on coated steel samples to produce surfaces that are harder and more wear and corrosion resistant. Carbon fibers that have been exposed to concentrated sunlight have also demonstrated increased oxidation resistance and increased strength.

Fuels and Chemicals. Photolytic effects combined with high temperature have been used in the laboratory to convert chemicals into fuels or fuel additives. This process, called chemical synthesis, offers the potential for tailoring chemical reactions to produce a wide range of high-value products. Using this approach, solar thermal technology could supply the energy to liquefy coal. The combination of extremely high temperatures, rapid heating, and high-energy photons breaks down the carbon polymers in coal,

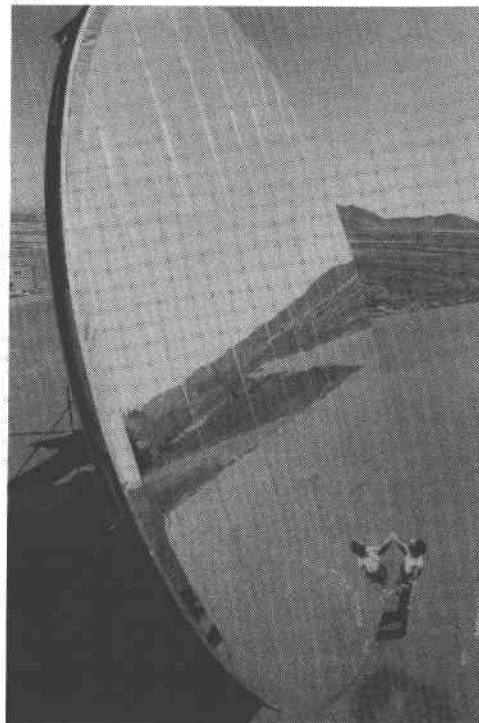
increases the liquid yield, and removes impurities, such as sulfur, from the final product.

TECHNOLOGY DEVELOPMENT

Technology development efforts translate research results into essential prototypical hardware that enables industry to approach a broad range of market opportunities with proven, high-quality, cost-effective, and reliable hardware. DOE/industry cost-sharing of the development of key components to reduce risk, enhance U.S. industry competitiveness, and to verify performance, manufacturability and reliability is sought. Such mutually beneficial, industry-cost-shared development projects leverage DOE R&D funds and build on research areas with strong industry interest and the promise of near-term commercialization. Typical activities in this category include building and testing small quantities of prototype heliostats, evaluating industry-developed advanced Stirling engines, and conducting proof-of-concept experiments with specific hazardous wastes.

Current technology development activities center on innovative approaches to reducing cost and improving the performance of key solar components. They include:

*Prototype Stretched
Membrane Heliostat*



Concentrator Development. The solar concentrator is the most costly component of a solar energy system. Stretched-membrane heliostats and dishes, in which the conventional glass mirror reflector and its supporting structure are replaced by a thin reflective membrane, offer the potential for low cost as well as high performance. The stretched-membrane concentrator is a more efficient structure than conventional designs and results in reduced material requirements and lighter weight. Prototype stretched-membrane heliostats have been built and are currently being evaluated. Conceptual designs of membrane dishes exist, and first prototypes are being built.

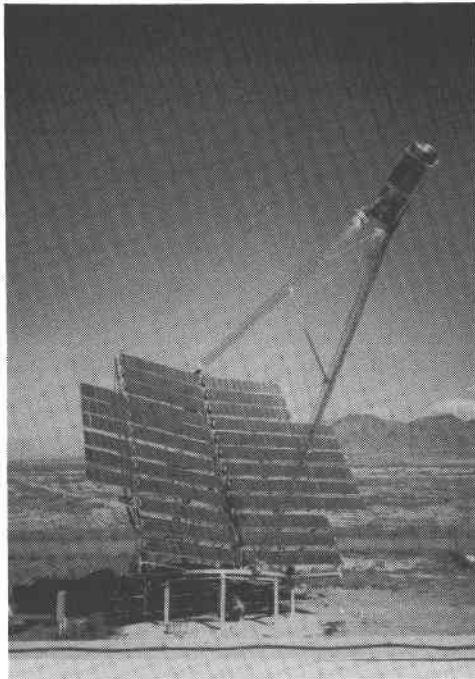
Molten-Salt Receivers and Transport Components. The performance and reliability of the receiver are key issues in further improving the cost and performance of central receiver plants. Industry is currently sharing the cost to develop tubular, molten-salt receivers and transport system components with DOE, and an experiment to test an advanced molten-salt receiver panel is being planned.

Direct Absorption Receiver. Research and development are underway to explore the use of a thin, absorbing salt film as the receiver in central receiver systems. This receiver will be more reliable because it contains no tubes and will demonstrate higher performance and substantially lower cost because of its reduced size. Laboratory and field experiments are currently being conducted to establish the flow characteristics of the molten-salt film and the absorption of the solar flux.

Sodium Reflux Receiver Development. An advanced sodium heat-pipe receiver for ultra-high solar flux applications is currently being developed. This receiver is much simpler than conventional tubular receivers and provides more uniform heat flux and temperature distributions. Because of its simplicity and thermal characteristics, the sodium heat-pipe receiver promises significant improvement in performance and reduction in the cost of dish systems. A prototype heat-pipe receiver has been developed and is being tested.

Focal-Mounted Engine Development. An efficient, low-cost heat engine capable of being mounted at the focal point of a dish collector is necessary for dish-electric systems. Among engine technologies, the Stirling engine offers the best potential for high efficiency and the cost reductions necessary for dish-electric modules to be competitive with conventional sources of electric power. Systems integration and testing of dish-Stirling modules are underway. Advanced Stirling engines and chemical conversion processes are attractive because of a large reduction in moving parts and the potential for low maintenance costs. The R&D of these advanced engines is being pursued with substantial industry cost-sharing.

*A Dish-Electric
Module Under
Test*



Testing and Evaluation. DOE has provided testing of components and systems at its Solar Thermal Test Facility and will continue to do so in the future. Examples of tests currently being performed or scheduled in the near future are; stretched-membrane heliostats, a tubular molten-salt receiver, advanced dish collectors, a sodium heat-pipe receiver, and Stirling engines. The tests provide critical information to DOE and industry on the performance and reliability of the components and systems and establish the readiness of a given component or system. Once developed, these components will have a dramatic impact on both the reliability and cost of solar thermal systems. Systems that include these components will be able to generate electricity at the 5-8¢ per /kWh level.

System and Application Studies. As new technology develops, the experience base with solar thermal systems broadens, and the marketplace evolves, it is essential to understand how they impact the design, effectiveness, and economics of solar thermal systems. In this regard, a key ongoing activity has been the assessment of central receiver technology by utility/industry study teams. This work is aimed at developing information necessary for planners and the investment community to facilitate private sector investment in commercial power plants.

These ongoing core research and development activities in the DOE Solar Thermal Program continue to provide lower cost, higher performance components for solar thermal systems and to develop new applications for the technology. Some examples of how DOE R&D and technical assistance have enabled industry to enter the commercial marketplace are described in the following section.

PROGRESS IN COMMERCIAL APPLICATIONS

Getting energy technologies from the stage of inception to the point that they become major players in the energy market is a long-term effort. An energy technology usually takes decades to reach its market potential. Such was the case with diesel power, hydropower, nuclear power, and others. And such will be the case for solar thermal energy. In a cooperative endeavor, government and industry must guide solar thermal technology from its initial research phases through commercial application.

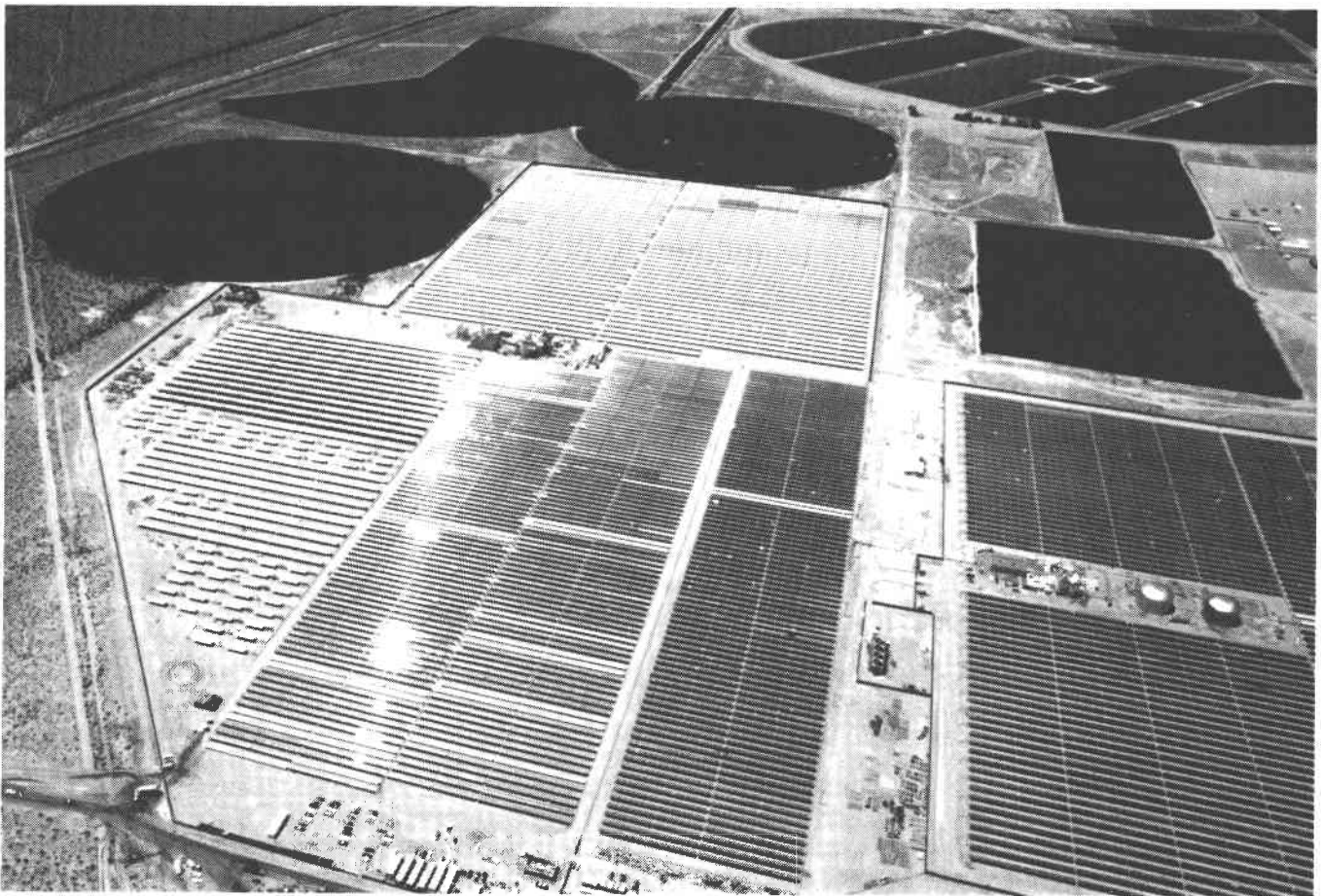
Over the past decade, the DOE, universities, and private industry have worked together to show that solar thermal systems are technically viable for generating electricity and for producing heat. In fact, one of the major collector technologies, parabolic troughs, is being used in major electric generation installations. Other solar thermal technologies for electric generation, parabolic dishes and central receivers, are also steadily moving in that direction.

THE DEVELOPING MARKETPLACE

Industry in the United States is already making measurable progress in bringing the results of DOE's R&D efforts to the marketplace (see Inset titled **Commercial Solar Thermal Systems**). Such commercial applications of solar thermal technology have occurred through a process that begins with research. The enabling research and the technology development activities result in components and integrated systems. Once component performance has been established, components are tailored by industry for specific applications, and prototypes are assembled into systems to validate near-commercial-scale operation in the specific application. Each step in this process further refines the technology and provides feedback for continued improvements. Cooperative efforts between DOE and industry occur at each step in this development process.

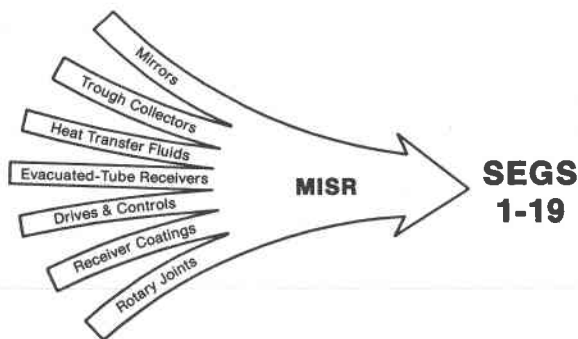
This process is exemplified by trough technology development and its application to electricity generation by Luz International, Limited. This is one of solar thermal's most impressive success stories. Luz, using trough technology based on R&D by the DOE, is installing 19 generating plants in Southern California. These

plants rely on thousands of trough collectors to provide heat conventional turbine generators. Solar energy is supplemented by a small fraction of natural gas to take advantage of the peak demand rate structure. Contracts are in place to supply a total of 500 megawatts of electricity to the Southern California Edison utility. About 130 megawatts of electricity is already being supplied by 5 SEGS plants. Moreover, Luz is investing in research and development in all areas, including storage technology, to refine the technology and to reduce the use of natural gas.



The Solar Electric Generating Station (SEGS) at Daggett, California

As illustrated below, innovations in materials and components for parabolic troughs were integrated into and proven by the DOE Modular Industrial Solar Retrofit (MISR) systems. These enabling technologies encouraged Luz to employ these component improvements in its commercial systems. As innovations were incorporated into successive commercial systems, each new generation reflected lower system capital costs and lower energy production costs as illustrated. Luz is now considering further reductions in cost by replacing hybrid solar/gas steam generators with storage systems currently under development by DOE. Specific feedback of this kind is incorporated into the DOE research and development program and strengthens industry's ability to continue deployment of systems in broader applications with increased user confidence.



Commercial Solar Thermal Systems

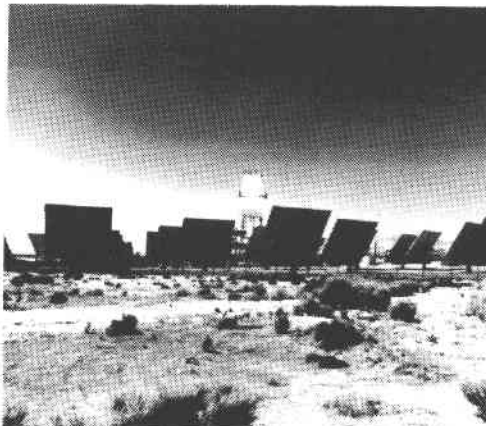
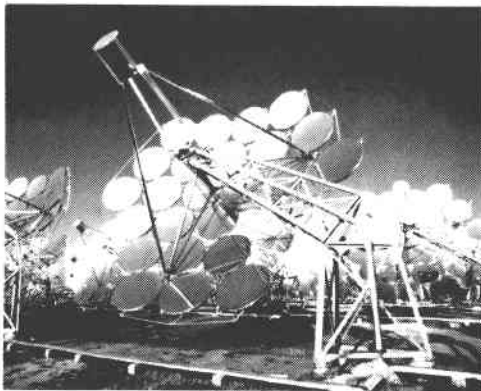


Such processes, in the longer term, also allow solar thermal systems to enter advanced applications such as hazardous waste destruction, materials processing and fuels and chemicals processing. While prototype solar thermal systems have not been tested in these applications, industrial manufacturers of concentrators have begun to see how the low-cost membrane dish concentrators and central receiver technology can directly be used to conduct chemical reactions in a receiver/reactor. Laboratory data have encouraged industry to begin to develop plans and assess the market potential for integrating solar thermal systems into these emerging applications which have national importance.

Commercial Solar Thermal Systems

Already there are over 140 Megawatts of installed electric generating capacity using solar thermal energy. This capacity is expected to grow to over 500 Megawatts in the next few years. These power plants, which are 100% privately financed, operate in areas of high solar insolation and produce energy for local loads or sell electricity to utilities under long-term purchase agreements.

140 Megawatts in Operation.....



And More On The Way.....

Luz International SEGS Systems. The most noteworthy examples of technology transfer from the DOE Solar Thermal Program to industry are the Solar Electric Generating Systems (SEGS) of Luz International Limited. As described earlier, Luz based its designs on technology developed in the DOE Solar Thermal Program. Luz designed, installed, and operates five parabolic trough solar electric power plants totaling 134 MWe. Systems to deliver another 60 MWe are currently under construction. The investor-owned projects are connected to the Southern California Edison grid under long-term power purchase agreements. Over a five-year period the performance and reliability of the systems have been substantially improved, and the cost of the solar field has been reduced by a factor of over two. Luz has two more 30 MWe projects in the design and construction phases and has long-range plans for 12 more plants in the 30 to 80 MWe capacity range. When completed they will represent an investment of nearly \$ 1 Billion. Additionally, projects in India and Israel are planned. Luz is investigating the use of both dish and central receiver technology in future projects.

LaJet SOLARPLANT 1. The LaJet Energy Company designed and built a 5 MWe solar power plant near San Diego, California. The dish concentrators are made from 24 polymer film facets that focus the solar energy onto a receiver. The plant uses 700 dish concentrators to produce steam that is transported to a centrally located turbine generator. LaJet has used silvered polymer film technology developed in the DOE Solar Thermal Program to improve the performance of their collectors by about a factor of 3. This project feeds power into the San Diego Gas & Electric grid under a long-term power purchase agreement.

ARCO Enhanced Oil Recovery Plant. ARCO Solar Incorporated funded, built, and operated a 1 MWt solar central receiver plant to produce steam for injection into existing oil wells. The hot steam heats the heavy crude oil reducing its viscosity and increasing oil production. The components used in this plant were directly adapted from products developed in the DOE Solar Thermal Program. A major accomplishment of this system was the demonstrated automatic operation of a solar central receiver plant without on-site personnel.

We cannot predict exactly where solar thermal technology will be most successfully applied during the next few years. However, the business plans and projections of companies involved in solar thermal technology give us insight to what most likely lies ahead (see inset titled **The Promise of a Developing Marketplace**). We have used those insights to guide the federal R&D program and to identify the following critical technical assistance efforts needed to support industry's entry into these markets. They indicate pursuit of near-term opportunities for electric power generation in the Southwest and in a variety of remote sites and for process heat applications in locations such as the Caribbean. Solar destruction of hazardous wastes is another exciting potential high-value application of the technology. Development of the receiver, reactor, and conversion processes for such advanced applications are currently emphasized in the DOE R&D program.

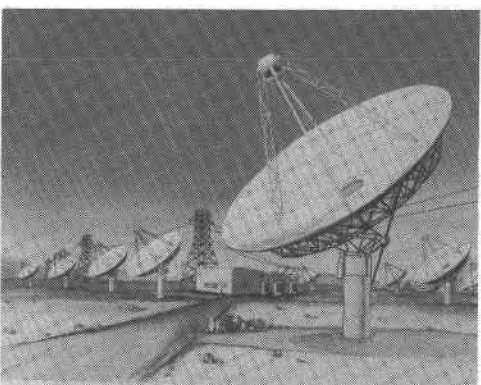
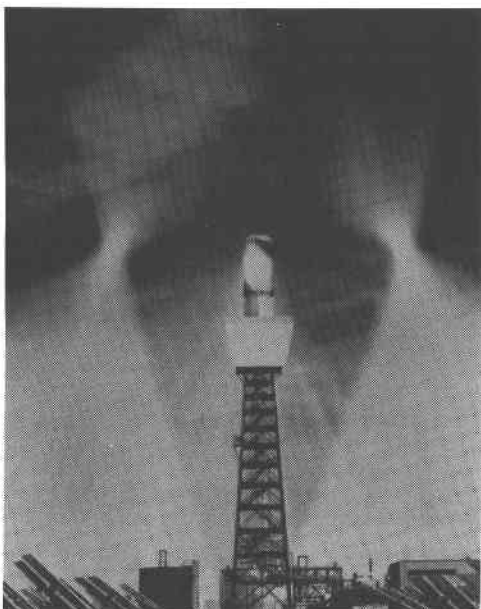
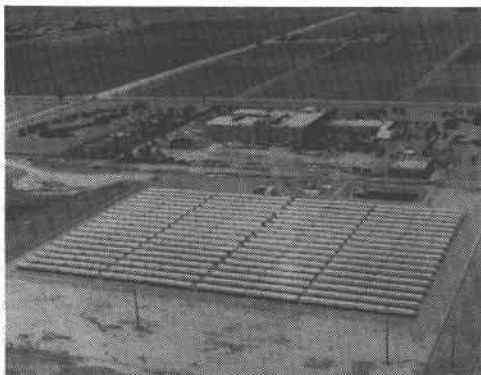
ASSISTANCE FOR COMMERCIAL APPLICATIONS

Technical assistance to industry has been provided in many ways and has been instrumental in the effective transfer of technical information, and information on new opportunities in the market. Timely availability of technical information, such as analysis codes and system design handbooks, identification and investigation of new opportunities in the marketplace through advanced application studies, and an increased emphasis on system design assistance to industry and government agencies, are some of the ways in which assistance will continue to be provided to industry.

Technical Assistance. A vital element of industrial assistance efforts is to work directly with industry by providing consultation on technology status, application screening, component and system performance predictions and design tools and handbooks. Utilizing the experience base of personnel and facilities at the federal laboratories, components and systems can be evaluated. Independent evaluation establishes user confidence and provides feedback to R&D. Industry recently requested such support in assessing new storage materials and approaches and their integration into higher temperature trough systems. Another industrial request was to make available the optical and structural analysis techniques and computer programs developed by federal laboratory personnel for solar concentrators. These and other broader based activities designed to assist industry by providing consultation on technology status, application screening, and component and system performance predictions will be provided

The Promise of a Developing Marketplace

We cannot predict exactly where the technology will be applied most successfully during the the next few years. However, using the business plans and projections of industry and users, we can give some examples of what most likely lies ahead.



Central Engine Trough and Dish Systems. Current commercial solar thermal plants use the central generating concept, where a single turbine-generator is powered by a large field of solar collectors, to produce electricity for the grid. This approach has made market penetration possible because it minimizes the risk to the user by combining new solar thermal technology with proven electrical conversion components. These commercial systems have benefited from components developed in the Solar Thermal Program, such as optical films, selective receiver coatings, and heat-transfer fluids. Plants similar to existing central engine systems and utilizing advanced components are currently on the drawing board, and 500 MWe are planned for introduction within the next two years. These plants typically range from 5 to 80 MWe in size.

Commercial Central Receiver Plants. Central receiver technology is ideally suited for intermediate and peak power generation and has been successfully demonstrated at the Solar One Pilot Plant. Significant advances have been made in heliostat and receiver technology since Solar One. Current-generation plants would use advanced molten-salt-tube receivers and large-area glass/metal heliostats. Industry/utility study teams have identified the need for a 10-30 MWe commercial project to verify the current technology at a scale larger than component tests but smaller than projected commercial power plants. Next-generation plants will likely use stretched membrane heliostats and advanced falling-film direct-absorption receivers. International cooperation in central receiver technology development also offers the opportunity for cost and risk sharing.

Dish-Electric Utility Applications. A dish-electric system uses a heat engine mounted at the focus of dish concentrator, eliminating the need for a heat-transfer fluid throughout the field. Because these systems are modular, each dish-engine generates power independently, they promise low-cost, reliable, and high performance power generation for both utility-scale and remote or military applications. The successful commercialization of the technology requires further development of thermal receivers, point-of-focus engines, and low-cost, stretched-membrane solar concentrators. The business plan of one engine manufacturer is directed at the commercial sale of a product within 3 years and the sale of an advanced, high efficiency engine in six.

Process Heat Applications. As the technology continues to advance and costs are reduced, additional spin-off into process heat applications is expected. For example, it is likely that central receiver technology (exactly as utilized in utility power applications except for the electric power generation subsystem) will be used to provide steam for thermally-enhanced oil recovery and that parabolic trough systems will find additional markets in process heat applications, such as export and remote markets, where conventional energy sources are at a premium.

Advanced Applications. Future markets will make use of the unique properties of high-intensity solar energy to induce photolytic reactions. Preliminary research has shown that highly concentrated solar flux can be used to effectively dispose of hazardous wastes and remove ground water contaminants. Such high-value applications are expected to find significant early markets. Highly concentrated solar flux can also potentially be used for materials processing and chemicals and fuels production. These applications will require advanced R&D of components, systems, and processes and represent long-term potential markets for solar thermal technology.

on request and should enhance U.S. industry's ability to bring improvements of existing systems to the marketplace with higher confidence of success and better expectations of meeting the challenge of international competition.

Committee on Renewable Energy Commerce Trade (CORECT). A multiagency working group to support U.S. industry in facilitating the use of U.S. renewable energy technology in worldwide applications is already in place. Created by Congress in the Renewable Energy Industries Development Act of 1983, CORECT has focused primarily on export markets to make available to U.S. industry information and technical assistance directed toward potential users. Through this program, important information on export markets and domestic opportunities for renewable technology allows U.S. industry to clearly assess the market potential and establish the relevance of their technology to the specific applications. CORECT-generated data will be used more fully to target specific solar thermal system applications and to assist U.S. industry in exploiting commercial opportunities.

Solar Technical Information Program (STIP). This program exists to support the renewable energy technologies. Through it, currently available information on Solar Thermal Technology experiences from various projects and applications is made available to U.S. industry and end-user communities. Information products are targeted to the audience that is most likely to use the data and benefit from the application of Solar Thermal Technology. Examples of such information products are an annual progress report, project summary report, science and technology briefs, user facility description, and general and special topic reports for particular audiences. This information will be tailored to assist U.S. industry by increasing awareness of and familiarity with solar thermal technology and its successful applications.

JOINT VENTURE PROJECTS

Introducing new energy technology into the marketplace could take the form of joint venture projects that spread any risk among a number of participants. Such projects would allow the supplier, user, and investment communities to gain essential experience with the design, performance, operation, economics, and financial requirements of a developing technology. Limited, carefully structured federal program participation in such activities would

encourage private sector investment, provide beneficial linkage the R&D efforts, and would be instrumental in technology transfer.

An example of the planning for possible future system applications is the multi-year activity for the assessment of central receiver technology by utility/industry study teams. The results of these studies indicate that central receiver technology is competitive with other alternative clean fuel energy options being considered in the 1990s. The study teams are now investigating the best approaches to mitigate the risk associated with initial commercial plants. In this phase, a key element is developing information necessary for planners and the investment community to facilitate private sector investment in commercial power plants. Luz International has been particularly interested in this phase and has been cooperatively investigating options with the study teams. It is anticipated such multi-year study processes will be repeated as other technologies come closer to large-scale commercialization.

To summarize, the continuing progress of the DOE Solar Thermal Program is bringing systems for electric generation and heat for industrial processes to domestic and international markets, and a number of additional opportunities exist in the near future. Increasing international competition, however, is already beginning to challenge the ability of U.S. industry to export technology to countries where demand for electric and heat energy is increasing much faster than in the U.S. The process above outlines specific actions to assist U.S. industry in meeting this challenge and in applying solar thermal technology to help solve this nation's energy problems through the use of an inexhaustible source of energy -- THE SUN.

REFERENCES

1. Energy Security: A Report to the President of the United States, United States Department of Energy, DOE/S-0057, March 1985.
2. National Energy Policy Plan, United States Department of Energy, DOE/S-0040, 1985.
3. Renewable Energy R&D Outlook, United States Department of Energy, Office of Conservation and Renewable Energy, Vol. 1, February 1985.
4. Electric Power Supply and Demand for the Contiguous United States, 1987-1996, United States Department of Energy, February 1988.
5. Annual Outlook for U.S. Electric Power 1987: Projections Through 2000, United States Energy Information Administration (EIA).
6. Electricity Capacity Supply and Demand, 1986-1995, North American Reliability Council (NERC).
7. New Electric Power Technologies, U.S. Congress Office Of Technology Assessment, 1985.
8. Hazardous Waste: Where To Put It?, M. Crawford, Science, Vol 235, p. 156-157, January 1987.
9. National Solar Thermal Technology Program, Five Year Research and Development Plan 1986-1990, United States Department of Energy, DOE/CE-0160, September 1986.

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