CONF-970701--3

SAN097-1240C

SAND--97-1240C

A LONG-TERM STRATEGIC PLAN FOR DEVELOPMENT OF SOLAR THERMAL ELECTRIC TECHNOLOGY

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ABSTRACT

Solar thermal electric (STE) technologies — parabolic troughs, power towers, and dish/engine systems — can convert sunlight into electricity efficiently and with minimum effect on the environment. These technologies currently range from developmental to early commercial stages of maturity. This paper summarizes the results of a recent strategic planning effort conducted by the U.S. Department of Energy (DOE) to develop a long-term strategy for the development of STE technologies. The planning team led by DOE included representatives from the solar thermal industry, domestic utilities, state energy offices, and Sun♦Lab (the cooperative Sandia National Laboratories/National Renewable Energy Laboratory partnership that supports the STE Program) as well as project developers. The plan was aimed at identifying specific activities necessary to achieve the DOE vision of 20 gigawatts of installed STE capacity by the year 2020.

The planning team developed five strategies that both build on the strengths of, and opportunities for, STE technology and address weaknesses and threats. These strategies are to:

- Support future commercial opportunities for STE technologies
- Demonstrate improved performance and reliability of STE components and systems
- Reduce STE energy costs
- Develop advanced STE systems and applications
- Address nontechnical barriers and champion STE power.

The details of each of these strategies are discussed below.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

INTRODUCTION

Solar thermal electric (STE) power is generated using heat from the sun. Solar collectors concentrate the sun's energy to produce temperatures between 350° and 800°C; this thermal energy is converted to electricity using conventional or advanced heat engines. Although U.S. industry has many options for designing a solar thermal system, the following three major types of technologies are currently under development:

<u>Trough systems</u> use linear parabolic concentrators to focus sunlight on receiver tubes located along the focal line of the concentrators. A heat transfer oil is then heated to around 350° –400°C and used to produce steam to drive a conventional turbine/generator. Trough power plants have been in commercial use in California for more than a decade, with 354 megawatts of electric (MW_e) capacity in nine plants ranging from 14 to 80 MW_e each.

<u>Power tower systems</u> concentrate sunlight using a field of heliostats that individually reflect solar energy to a thermal receiver mounted on top of a centrally located tower. Although many working fluids and a range of temperatures are possible, U.S. industry favors collecting the solar heat in a nitrate-salt working fluid, which doubles as a storage medium. When electric power is needed, steam is generated from heat stored in the salt,the steam then powers a conventional turbine/generator. Although there are economies of scale for all power tower systems, they are usually considered for installation of 100 MW_e and larger. Installations as small as 30 Mw_e, however, may be economic

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for some designs. Power towers have never been used in commercial applications, though a number of demonstration and pilot plants have been constructed worldwide.

Dish/engine designs take a modular approach to build a complete power system at a scale of 5–50 kilowatts of electricity (kW_e). This approach uses a parabolic reflector with a high concentration ratio, focusing sunlight on a receiver/engine package mounted at the focal point. Most systems under development today use a kinematic Stirling engine, with Brayton-cycle engines as an alternative. Dish/engine systems are currently undergoing rapid design evolution, with the first commercial sales possible within a few years.

The U.S. Department of Energy (DOE) envisions a world in which STE technologies are a significant and growing part of the global energy supply picture. According to this vision, these technologies will provide environmentally sound power to the utility grids of the world and touch the lives of millions of people who would otherwise be without electric power. One key measure of success in reaching this vision would be the installation of 20 gigawatts (GW_e) of solar thermal electric power by the year 2020. Although the world energy market for solar thermal electricity will be provided by a number of multinational companies, the DOE program works to ensure that U.S. industry will be the market leader in supplying STE technologies.

In 1996, DOE began to develop a 20-year strategic plan to identify a new set of goals and strategies for its STE program. The need for this strategic plan was driven by three factors. First, a number of multiyear technology development projects were coming to successful conclusions and raised the question "What's next?". The second factor was the markets for STE technology. The rapidly emerging deregulation of the U.S. utility industry is changing domestic markets for electricity with a speed unparalleled in history. The third factor was tremendous changes in the competing energy technologies. For example, in little more than a decade the United States has gone from tremendous concern regarding natural gas availability (including converting natural gas power plants to coal firing) to having historically low natural gas prices, highly desirable combined-cycle technologies, and the widely held perception (right or wrong) that natural gas will be inexpensive for a long time to come.

The process that DOE used to develop the strategic plan began with input from technology experts in industry and Sun♦Lab, the interlaboratory organization created by the partnership of the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories. DOE then chaired a steering committee that included both DOE and Sun♦Lab staff to use this input to formulate and write several draft versions of the plan. These drafts were then reviewed by key stakeholders before the final version was produced.

THE STRATEGIC CONTEXT

The DOE steering committee used an analysis of the strengths, weaknesses, opportunities, and threats (SWOT) to set the stage for making decisions on the future direction of the program. The SWOT analysis is a common process in strategic planning, providing a framework to categorize a wide array of inputs from technical experts in a way that facilitates decision making. The key results from the SWOT analysis are described below.

Strengths

In a world with growing demands for environmentally benign power, solar thermal electricity has the advantage of being the least costly solar electricity for grid-connected applications available today. Measured from actual installed systems, the most recent 80-MW trough plants produce electricity with a levelized energy cost (LEC) of about \$0.12/kWh. This is one-half to one-third of the price of electricity produced from photovoltaic (PV) installations today. Projected costs for emerging technologies are even more attractive. Molten-salt power tower systems, which have been successfully demonstrated at the 10-MW_e, pilot-scale Solar Two plant, promise higher efficiencies and lower costs than trough systems. Several studies of the molten-salt power tower system have projected energy costs of \$0.10/kWh for the first plant, with costs ultimately declining to less than \$0.05/kWh. New hybrid gas/solar system designs of these technologies also show promise for substantial reductions in the cost of electricity in the next few years. The integrated solar combined-cycle system (ISCCS) for trough systems uses natural gas combustion in a combined cycle, adding solar heat in the bottoming cycle. Another design, the Kokhala concept for power towers, also uses both natural gas and solar heat in a combined-cycle energy conversion system. Both of these systems show promise of reducing the cost of solar electricity (without factoring in dilution of the cost by cheap natural gas) by 50% or more.

Using a thermal process to generate electricity allows STE plants to cheaply and efficiently extend operations beyond daylight hours, so that plants can be as dispatchable as conventional fossil-fueled plants. Molten-salt power tower systems can incorporate inexpensive thermal energy storage to provide operational flexibility. Hot salt can be stored for hours or even days with efficiencies of 98% or more, allowing flexibility for operations through weather transients and into evening hours. The amount of storage can vary between fractions of an hour to 18 hours, depending on the capacity needs and load profile of the utility application. Another option to achieve operational flexibility is hybridization, using fossil fuels as a backup for solar energy. Storage and hybrid operations allow for a firm capacity value of STE plants and for production of electricity at times when it has the highest value, and reduce the overall LEC of the plant by amortizing fixed costs over more kilowatt hours of power production. These advantages have all been demonstrated in the market: all of the commercial STE plants built to date have been hybrid systems that achieved high dispatchability and reliability, and that produced power during peak demand hours.

Another strength of STE technology is that is has been proven in commercial application in a utility setting. To date, the nine operating parabolic trough plants in California have generated over 6 million MWh and continue to operate reliably. These plants have demonstrated the long-term performance of the key solar components including concentrators, receivers, controls, and thermal energy transport. The plants have also demonstrated the validity of cost reductions through learning, manufacturing improvements, and economies of scale. Energy costs for the initial trough plants were over $0.20/kWh, which declined by nearly 50% in less than a decade.

Weaknesses

The most critical weaknesses of STE technology are related to high current costs. In the last decade solar thermal power costs have dropped significantly; however, the current (and projected) cost of natural gas in most markets has decreased even faster. To illustrate this point, when the first commercial trough plant was constructed by LUZ International, Ltd., in 1984, the avoided cost of electricity in Southern California was about $0.10/kWh, and the cost of electricity from the trough plant was around $0.20/kWh, or a factor of two more expensive. In mid-1997 the value of electric energy in Southern California is around $0.025–0.03/kWh, whereas the best solar thermal electric system would produce electricity at $0.08–0.10/kWh.

To merely focus on the electricity price from STE technologies is to miss some other cost-related weaknesses the technology currently has. Another issue is the high capital cost of the technology compared to that of fossil fuel systems. This is an intrinsic feature of STE power plants, one not likely to ever be totally eliminated, because with an STE plant the owner must purchase not just the energy conversion equipment (as a fossil fuel plant does) but also the solar hardware for collecting and using the energy. The solar field represents, in essence, a 30-year supply of fuel for the power plant that the fossil fuel plant does not pay for in the initial cost of the plant. From a pure life-cycle-cost standpoint, high capital costs are not a problem if they are offset by lower operating costs, but from a pragmatic standpoint, this is a barrier today. For a variety of reasons (including tax codes, financial barriers, company structures, and current energy market structures), owners generally prefer plants with lower capital costs, all other factors being equal.

Another weakness related to cost is manufacturing cost of solar components. Much more than 50% of the current cost of solar thermal systems is related to manufacturing concentrators, receivers, and other solar components. As with any other manufactured goods, the cost for these items tends to be strongly related to production volume: higher volumes result in production economies and lower costs. In the long term, constant and high demand for solar systems will allow manufacturing economies of scale that can reduce costs by a factor of four or more from today's levels. However, with today's uncertain markets it is extremely risky for industry to tool up for solar manufacturing. Hence, the high cost of solar components has remained a major contributor to the high cost of the technology.

Another weakness that affects emerging STE technologies is limited operating experience. Although this does not apply to the trough technology developed by LUZ (which has many years of reliable operating experience), newer technologies such as power towers, dish/engine systems, and advanced trough designs such as the ISCCS and direct steam generation have been demonstrated but do not have long-term reliable operating experience. Although this is likely to change in the next few years, it currently is a weakness for the technologies in entering the market.

Opportunities

There are a number of near-term opportunities for commercial development of solar thermal technologies. These opportunities generally involve either niches within existing markets or are related to growing concerns about the impact of energy development on the local and global environments. And even though these are not necessarily large or stable markets, they represent openings for initiating commercial deployment of STE technology.

International markets offer numerous opportunities for STE deployment by U.S. industry during the next 10 to 20 years. The benefits of these markets are significant. Not only will export markets create U.S. jobs, but they also help reduce costs for domestic applications through economies of scale and technology advancements. These markets are attractive for STE today because of their significant differences from the U.S. energy market. Currently, more than 40% of the world's population is without power. Asia and Latin America will experience some of the highest growth in power needs in the near term. Dish/engine systems provide an attractive alternative to diesel generator sets in village and remote power markets. Many of the developing countries with large power needs have sites with high direct-normal solar resources; examples include India, Indonesia, Mexico, Egypt, China, South Africa, Argentina, Brazil, Pakistan, and Turkey. An additional feature that helps to make these sites attractive is the availability of financing incentives. Key development and financial institutions (such as the World Bank and its Global Environment Facility [GEF]) are beginning to consider renewables in their technology portfolios for new power projects in developing countries. The GEF in particular has established a program of providing up to $50 million in subsidies to solar technologies to facilitate their market entry.

Niche markets exist where fuel prices are high or in which economic value is placed on the renewable aspect of energy.

There are several of these possible market opportunities, including:

- High-value markets such as line-support (domestic) and industrial customers with the need for reliable power (in developing countries).
- Domestic and international locations that lack the infrastructure to take advantage of low-priced fossil fuels, but have good solar insolation.
- Integration of STE technologies with other renewable energy resources. For example, STE systems could provide a good addition for countries that use a large amount of hydropower, because solar electricity output increases during dry seasons and dry years when hydropower output is low. They could also be added to many wind farms to increase daytime or dispatchable power capabilities.
- Domestic and international utility set-asides for renewable energy projects such as those implemented or proposed by some states and solar enterprise zones (e.g., California, Arizona, Nevada's Corporation for Solar Technology and Renewable Resources [CSTRR], and Rajastan in India).
- Recognition by a number of western U.S. states that their region should seek to supply 10% of its electricity from renewable sources by 2005 and 20% by 2015.

Although utility restructuring in the United States will increase competition and decrease prices of electricity, a side benefit of restructuring for STE technologies will be allowing customer choice for their power supply. Utility restructuring may facilitate the emergence of "green power" markets, allowing STE technology to grow in the U.S. market without having to compete against fossil fuels solely on the basis of cost. A number of recent market surveys conducted by electric utilities and others indicate that 10% of their customers are willing to pay an average of 15% higher electric bills to improve the environment through the use of renewable energy. Green pricing has been introduced in five utility service areas and proposed in eight others, and similar programs have been adopted by municipalities in several European nations.

<u>Threats</u>

The most significant threat to STE technology is that it may become irrelevant in the energy market. With no current commercial sales it is possible that the market for "green power" will become saturated by other renewables. At the same time, the market for energy as a whole is a fiercely competitive one, with fossil-fuel technologies continuing to improve in both efficiency and cost. Significant cost reductions and the ability to capture larger market shares require sales of STE in the marketplace.

The price of fossil fuel is a real threat. Natural gas is currently widely available and inexpensive, and is expected to stay that way for at least 15–20 years. Reserves of other fossil fuels are also substantial, although environmental concerns may eventually restrict their use.

STRATEGIC DIRECTIONS FOR THE FUTURE

The challenge that emerges from the SWOT analysis is how to further drive down the costs of solar thermal technology while avoiding losing major market opportunities to competing technologies and/or foreign industry. The strategies selected are designed to meet both of these needs. By supporting near-term opportunities, U.S. industry can provide commercial validations of the most recent solar thermal technologies. This will help to establish the technologies in the market, but at the same time will provide the opportunity to prove and further develop them. The most immediate challenge then becomes helping U.S. industry to exploit near-term opportunities in high-value niche markets. This market foothold will provide manufacturing experience that allows cost reduction. It will also provide a true commercial environment to prove the validity of advanced components developed through research and development (R&D). In the longer term, as industry enters bulk-power markets, the programmatic emphasis can shift to providing specialized, high-technology engineering and long-term R&D in support of advanced and innovative new technologies.

The five strategies discussed below will help DOE to fulfill its mission and achieve its vision.

<u>Strategy 1. Support the next commercial opportunities for STE technologies.</u> STE's most critical near-term need is to build plants in order to establish the costs and performance of the current generation of STE systems, which are substantially better than those of the existing parabolic trough systems operating in California. Operating systems in commercial environments prove the true readiness of the technology in a way that demonstrations and pilot plants cannot. These systems will also facilitate future cost reductions by building up manufacturing volume, increasing learning effects, and reducing bid and overhead costs for industry. The profits from construction and operation of the plants will provide industry with funds for reinvesting in R&D, which can be leveraged with DOE investments. As described earlier, a number of viable new opportunities for solar thermal power plants are on the horizon, including World Bank opportunities in India, the Solar Enterprise Zone in Nevada, and various state government initiatives in California, Arizona, and Nevada.

The DOE role in this strategy is a critical one, but one that must support and follow industry leadership. As industry develops opportunities for projects, DOE will provide the unique capabilities of Sun♦Lab to respond to industries' need for technical assistance. Examples of this expertise include systems analysis, performance estimation, resource assessment, and other critical support. DOE will also use Sun♦Lab to provide design assistance, test and operation and maintenance (O&M) expertise, and other specialized technical support on an as-needed basis to help ensure the success of industry technical projects.

Strategy 2. Demonstrate improved performance and reliability of STE systems and components. The emerging STE technologies hold the promise of being much less expensive than the trough technology installed in California. However, these technologies require substantial improvements in both performance and reliability to attain commercial success. These enhancements must be demonstrated on a scale that can convince potential users, regulators, and investors that solar thermal power can meet their needs. This will require continued improvements in component and system designs that can only be achieved through R&D and subsequent demonstration of performance. The program will work to produce these improved components and systems through collaborations with U.S. industry and in-house development at the national laboratories. One emphasis will be on the effort to develop solar/gas hybrid systems that can facilitate the penetration of near-term markets. The program's extensive test facilities and capabilities will be maintained and upgraded to meet the test and evaluation needs of industry. The program will also work with industry to do the necessary performance testing and evaluation, including the long-term and accelerated testing needed to validate system performance.

Strategy 3. Reduce STE energy costs. The capital and O&M costs of solar thermal technology must be substantially reduced to achieve the goal of 20 GW_e installed capacity by the year 2020. A significant problem lies in bridging the gap between early prototype production and mass production to reduce the cost of early builds. This challenge can be met by improving the manufacturability of current designs and developing the tools required for initial production. The program will support industry in developing these manufacturable designs and manufacturing capabilities and in gaining the experience needed to produce cost-effective prototype commercial systems. Technical support that takes advantage of the life-cycle manufacturing experience of the national laboratories, as well as cooperative research and development agreements, cost sharing, and contracts, will be used to support industry in this critical area through the Solar Manufacturing Technology initiative.

The program will continue to work to reduce the costs of O&M of STE plants by refining system components for use in the cyclic solar environment, and developing optimized O&M strategies. In addition, studies will continue to be conducted and system designs evaluated to better understand and optimize components. This will help guide additional R&D by identifying weaknesses and strengths and developing potential solutions.

Strategy 4. Develop advanced STE systems and applications. The expansion of STE into bulk-power markets requires advanced technologies that can only be developed through a vigorous, focused R&D program. The program will pursue advanced development of components and systems targeted to improve current systems. Areas such as alternative storage systems, engines and power cycles, and working fluids will be addressed. This work will be conducted in close collaboration with industry, ensuring that efforts are focused on the most pressing areas. In addition, the program will support research on high-risk, high-payoff "revolutionary" technology improvements, processes, and applications that offer the potential for dramatic improvements in performance, reliability, and cost. A small portion of program resources will be used to investigate advanced materials and concepts that the emerging solar thermal industry has neither the resources nor expertise to address.

Strategy 5. Address nontechnical barriers and champion STE power. Bringing any new technology to the marketplace is a difficult task. In the case of solar thermal power, many of the barriers cannot be overcome by technical advances alone. Various nontechnical issues, such as reduction of risk in support of low-cost financing, equitable tax treatment and energy pricing relative to other technologies, and recognition and acceptance of the value of solar thermal's environmental benefits, can play all-important roles in when–indeed, whether–a new technology such as STE can penetrate today's highly competitive energy markets. The program will work to evaluate and develop policy recommendations on tax treatment, energy pricing, environmental benefits, and innovative financing alternatives for STE. These activities will be carried out in new strategic partnerships with industry and organizations such as the World Bank, international energy developers, independent power producers, and environmental groups. These partnerships will help to expand the solar thermal industry base and promote solar thermal as a solution for energy and environmental problems worldwide.

CONCLUSION

The focused program of research, development, and demonstration (RD&D) that has been conducted during the past two decades–and the know-how resulting from this RD&D– has positioned STE technologies on the brink of broad commercial application. However, in order for these technologies to enter domestic and international markets, DOE must continue its efforts, both with industry and in the R&D arena, to reduce costs and improve reliability and performance, while also addressing the many economic and political barriers faced by any emerging technology. These efforts are part of DOE's plan to make U.S. industry a vital player in providing clean, economical energy throughout the world.