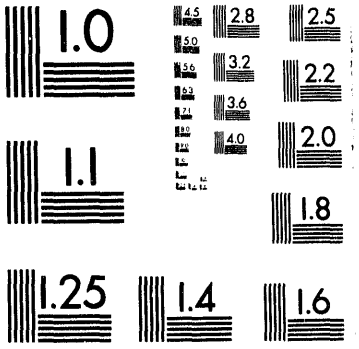
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Solar Activities at Sandia National Laboratories*

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Abstract

The use of renewable energy technologies is typically thought of as an integral part of creating and sustaining an environment that maximizes the overall quality of life of the Earth's present inhabitants and does not leave an undue burden on future generations. Sandia National Laboratories has been a leader in developing and deploying many of these technologies over the last two decades. A common but special aspect of all of these activities is that they are all conducted in cooperation with various types of partners. Some of these partners have an interest in seeing these systems grow in the marketplace, while others are primarily concerned with economic benefits that can come from immediate use of these renewable energy systems. This paper describes solar thermal and photovoltaic technology activities at Sandia that are intended to accelerate the commercialization of these solar systems.

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Introduction

Sandia National Laboratories supports the US Department of Energy's (DOE) programs developing photovoltaic, solar thermal, geothermal and wind renewable energy technologies. These technologies are particularly appropriate today because of the non-deleterious effect they have upon the environment, and the fact that they do not leave an environmental debt for those who follow us. In addition, they can contribute to the country's energy independence, curtail foreign energy purchases, and create domestic employment opportunities serving markets both at home and abroad.

Federal renewable energy technology development has been undergoing a metamorphosis during the last several years. It is no longer being conducted as a closed set of activities among DOE and its field laboratories, but as a series of partnerships involving all levels of government, commercial suppliers and developers, end users, and facilitating organizations that can influence the production, purchase, and use of particular types of energy systems. These partnerships address relevant issues in a timely manner and bring needed expertise to development projects in order to maximize chances for success and highly leverage all resources involved. There is a "market pull" to the development, rather than a "technology push," with the direction and magnitude of the pull being set by those who are best qualified to do so.

Sandia is leading the way in creating these partnerships. In the area of solar thermal electric systems, there are 50/50 cost-shared development projects totaling over $100 million in place at the present time. As a deployment side example, we have cooperated with energy offices in three states on applications for solar water heating at correctional facilities Our photovoltaic technology development efforts emphasize manufacturing innovations that will improve the cost, performance, and reliability of photovoltaic

devices and systems. Our photovoltaic design assistance activities are recognized and respected worldwide as effectively promoting the use of US photovoltaic products and services. We have demonstrated the capability to operate in foreign countries, working together with both US and host country governmental entities, international government groups, and various non-governmental organizations.

Solar Thermal Energy

Sandia's solar thermal energy technology development and deployment efforts look at two basic types of applications: those that produce electricity and others that provide useful thermal energy for industrial processes, including refrigeration. In addition to certain technical commonalties, each development also shares the fact that it is done in partnership with one or more manufacturers, users and/or enablers/facilitators. We leverage involved resources, create synergistic skill mixes, and determine priorities through these partnerships.

Electricity

Through the DOE Solar Thermal Electric Program, we are participating in the development of two major types of modular solar thermal electric systems--power towers and parabolic dish/engine systems. Partnerships are designed to commercialize these technologies before the year 2000 by combining the solar-specific experience base and analytical and experimental capabilities of Sandia with the manufacturing, marketing, and management skills of industry. Presently, five major 50/50 cost-shared cooperative activities, with a total value over $100M, are underway within the program, and more are being initiated.

In the power tower area, we have teamed with a consortium of nine utilities (led by Southern California Edison), industry, and DOE to initiate the $48M, 5-year Solar Two Project, a molten-salt retrofit of the 10-MW Solar One Pilot Plant. Solar Two will bring together molten-salt components previously developed at Sandia into a system demonstration of a complete power plant. The innovative molten-salt approach allows the collection of solar energy to be completely decoupled from the generation of electricity, thereby giving load-following capability to the operator and eliminating the sensitivity to cloud transients. Successful operation beginning in 1995 is expected to lead directly to the first 100-MW commercial power plants by the end of the decade.

We have three joint-venture programs in developing dish/engine technology. The first, a $14M, 4-year project with Cummins Engine Company, is targeted toward remote power markets both here and abroad, and is expected to lead to commercially available 7-kW systems within two to three years. These systems use three components/subsystems partially developed at Sandia that are considered advanced technology: 1) free piston/linear alternator Stirling engines, 2) stretched-membrane solar concentrators, and 3) alkali metal heat-pipe receivers mating the concentrator and engine. This particular system won an R&D 100 Award in 1993 as one of the most significant product developments of the year. The other two (one with Science Applications International Corporation and a second with Cummins) are aimed at providing 25-kW systems for utility applications. These approximately $35M (each), 5-year activities involve active utility participation throughout and should lead to commercial systems near the end of the decade. Plains Electric is expected to participate in both of these projects.

We work with solar power plant operators. The Kramer Junction Company operates five30-MW parabolic trough power plants in southern California. Our $7M, 3-year operations and maintenance (O&M) cost-reduction project takes advantage of 40 plant-years of commercial solar power park experience to reduce O&M costs and improve performance of all future solar plants. When the solar collectors at another power plant location suffered earthquake damage, our analytical capabilities were used to calculate the design for the structural modification to the collectors that would most cost-effectively prevent that type of damage from occurring again. When California power plant operators were confronted with a rapid 20% decrease in solar radiation, we determined that the decrease was due to pollution in the air caused by a volcano and that the condition would improve within a few years. Again, the broad and high technology capabilities of Sandia allow for unique contributions to be made in areas relating to increasing the use of solar energy systems.

Process Heat

Many of our contributions are not of the high-technology type, but nevertheless make the difference between a technology being economically practical or not. Much of our process heat work falls into this category. Here again we form partnerships. We worked with Industrial Solar Technologies of Denver, Colorado, and the California Department of Corrections to realize the installation of a hot water system to serve the needs of 1500 inmates in the correctional facility in Tehachapi, California. We provided objective, third-party technical consultation during the procurement process, supplied technical data and recommendations regarding wind-induced damage, and have characterized the performance of individual modules at our test facility.

In cooperation with Gould, Incorporated of Chandler, Arizona, we helped rehabilitate a solar plant providing hot water for a copper foil plating process. This rehabilitation is currently saving Gould management $10,000 monthly.

A two-day effort on the part of our Solar Thermal Design Assistance Center led to a recommendation that is saving the Veteran's Administration Hospital in Albuquerque about $6000 a year on its gas bill, and that may double soon. In 1985, the hospital put in a flat-plate solar thermal system to provide much of the facility's hot water. But the hot water it produced was far too hot, and the system's pressure relief valve kept popping, resulting in a loss of ethylene glycol. This led to the system being completely shut down by the next year. Our engineers determined that the system was too big for the load being serviced. Cutting the use of the existing field in half was the recommendation This was done, and the system has worked with no problem since that time. Now the hospital is looking for additional loads so that the unused half of the collector field can be reapplied and additional energy savings realized.

Refrigeration is another area where the solar thermal technologies can make valuable contributions. Efforts with Energy Concepts of Annapolis, Maryland, to develop intermittent solar absorption ice-making equipment has led to the installation and operation of this technology for the benefit of rural Mexican fishermen.

Photovoltaics

Photovoltaic power systems are among the most modular generators of electrical energy available. They can be sited almost anywhere in almost any size to produce electricity for

a large variety of applications, and have virtually no environmental impact while operating. The major barrier to greater market penetration is the high capital cost of these power systems. We are teaming with US industry to reduce these costs. Efforts involve reducing the costs through technological improvements and increased deployment leading to higher, more cost-effective production volumes.

Industry Focus

Sandia's photovoltaic program focus is on accelerating the commercial use of photovoltaic power systems. This is based on a close partnership with US industry. The technology base in engineering, materials, microelectronics, computing, and manufacturing that has been developed at Sandia in more than 40 years of service in the national interest is integral to this effort.

Cost, performance, and reliability affect market acceptance of photovoltaic power systems. How system component materials and manufacturing methods affect system cost, performance, and reliability is important to industry. Sandia's photovoltaic technology development and its evaluation activities provide feedback, which helps industry improve its products. Industry identification of requirements for new systems, which will allow photovoltaic technology to become acceptable for larger markets, provides direction for our programs. Development of the technology to exploit the new markets is a cooperative effort between industry and Sandia.

Types of Activities

Sandia's photovoltaic program has activities in all aspects of the technology, from cell development to photovoltaic power system applications, with emphasis in manufacturing

and deployment. The cell work is with the crystalline silicon solar cell industry to improve solar cell processing and develop new designs. Efforts are industry driven and include process changes to improve the cost effectiveness of cells through performance increases or cost reduction. Sandia is a member of the Multicrystalline Silicon Research Cooperative established in late 1992. The cooperative is a consortium of industry and government laboratories (Sandia and the National Renewable Energy Laboratory) to study processing and cell design issues specific to multicrystalline silicon solar cells. Industrial members include AstroPower, Crystal Systems, Mobil Solar, Solarex, and Texas Instruments. We are working on surface texturing and reflectance control, phosphorous-diffusion and aluminum-alloy gettering, hydrogen passivation, low-temperature surface passivation, process integration and advanced cell development. Advances will be made available to cooperative members, allowing these US industries to gain an advantage over their international competition.

We are developing a new cell concept in which a grid on the back surface contacts the current-collection junction (emitter) on the front surface. The cell structure eliminates shadowing losses on the front surface while maintaining good collection efficiency. Our concept uses a laser to drill a grid of closely spaced holes in the silicon substrate. Phosphorous is then diffused on the surface of the holes to electrically connect the phosphorous-diffused emitter on the front surface with a grid on the back surface. Hence, we refer to the new cell as the emitter wrap-through solar cell. We are developing two versions of this concept that use only low-cost production techniques that are already commonly available in photovoltaic production. Our modeling shows that the new structure has the potential to achieve efficiencies of 20% and 18% with solar-grade mono- and multicrystalline silicon 100 cm^2 solar cells, respectively.

In module development, we work with the photovoltaic module manufacturing industry to improve module performance, reliability, and lifetime. Improvements in module design, materials, and manufacturing are addressed. Capabilities now fully established in our Photovoltaic Technology Evaluation Laboratory were recently used to provide detailed characterizations of electrical, thermal, and optical performance of modules from Texas Instruments, Mobil Solar Energy Corporation, United Solar Systems Corporation, and the University of New South Wales. The three Texas Instruments modules tested were pre-production prototypes using the company's unique and copyrighted Spheral Solar cell technology. The electrical performance of these modules looks promising, and our testing provided additional information related to electrical mismatch losses, the optical influence of the spherical topology of the cells, and thermal expansion issues associated with one of their prototypes.

Our balance of systems development activities are helping industry develop and evaluate controller, power processing, and other balance of systems components.

Our engineers work with industry and user agencies to integrate photovoltaic and balance of systems components into photovoltaic power systems for specific applications. Laboratory and field tests on installed systems to evaluate systems performance and identify lifetime-limiting components of photovoltaic systems are integral to this work. Results of these tests are communicated to industry partners in ways that assure that proprietary information is protected.

Sandia's photovoltaic laboratories are for the development and evaluation of photovoltaic systems and components for industry and other members of the photovoltaic community. Facilities include the Photovoltaic Device Fabrication Laboratory, the Photovoltaic Systems Evaluation Laboratory, the Photovoltaic Device Measurements Laboratory, and

environmental test chambers and non-destructive test and analysis facilities developed at Sandia through defense programs.

Deployment Activities (Domestic)

Our work with utilities and government agencies is primarily concerned with identifying and demonstrating, with industry, cost-effective photovoltaic applications for these user agencies.

A recent example is a partnership effort with the Navajo Tribal Utility Authority to bring power to remote homes in the Navajo Nation. The Authority is investigating the use of photovoltaic systems in place of line extension for its more remote customers. These systems would differ from the others presently installed in that the utility would own and maintain them.

Sandia has constructed a mobile demonstration trailer and duplicate stationary unit to assist the Navajo agency with education and training in photovoltaic systems. The Tribal Authority will use the trailer to show would-be customers the types of systems it plans to offer; the stationary unit will be at Sandia's Photovoltaic Systems Evaluation Laboratory.

A second example involves the Dangling Rope Marina, located forty-five miles northeast of the Glen Canyon Dam on Lake Powell and accessible by only boat or helicopter. The marina currently uses diesel generators to provide its power-- source that is both costly, 38 cents a kilowatt-hour, and risks a possible spill on the lake because the fuel has to be brought in by boat.

Because of this remoteness, photovoltaic technology is being examined as an energy source to save costs in the operation of the marina. Toward this effort, Sandia has been providing assistance with feasibility evaluation, operational characterization, and general technical support for a proposed collaborative project to augment the generation by existing diesel engines with photovoltaic energy. Photovoltaics and the use of a battery/inverter system will improve the efficiencies of the Dangling Rope generation system.

We also work with the Department of Defense (DoD). Our Strategic Environmental Research and Development Program (SERDP) effort is helping the DoD improve the environmental performance of its electricity generation by working with industry to deploy photovoltaic systems at DoD facilities.

Deployment Activities (International)

The international activities work is with industry and with international and US government agencies to identify applications and deploy sustainable renewable energy projects worldwide. Working with the US Agency for International Development (USAID) in Mexico to assist Mexico in deploying renewable energy projects is complementary to our other international activities in Latin America and the Caribbean region supported by the Department of Energy, and provides an excellent example of how Sandia serves national renewable energy interests through enabling and facilitating international deployment.

During FY93, the US Agency for International Development (US-AID) earmarked $15 million to fund renewable energy projects consistent with its Global Climate Change

mission. In the spring of 1993, Sandia worked closely with the US-AID/Mexico office to develop a renewable energy project proposal, with support from Meridian Corporation as a subcontractor.

The proposal submitted by US-AID/Mexico put major emphasis on the identification, selection, implementation, and follow-up evaluation of projects demonstrating economically and socially productive off-grid applications of commercial renewable energy systems. The Mexico proposal was subsequently selected for $4 million of the FY93 funding for off-grid project development and implementation, and US-AID Mexico requested support for project implementation from the Department of Energy and Sandia.

During the fourth quarter of FY93, Sandia and Meridian worked closely with US-AID/Mexico to revise a plan under which the project would be implemented through the Department of Energy under Sandia leadership with collaborative support from the Pacific Northwest Laboratory and the National Renewable Energy Laboratory. The $4 million funding was distributed in September to the project participants to use over a three-year period, from FY94 to FY96.

The breakdown of funds is $3.625 million to Sandia for overall project management and implementation, $200,000 to Pacific Northwest for wind resource assessment, and $175,000 to the National Renewable Energy Laboratory for solar resource assessment and wind-component project support. All sums include Department of Energy overhead.

The Department of Energy, the Committee on Renewable Energy, Commerce and Trade, and the Americas 21st Century Initiative are providing additional cost-sharing funds for technical support through Sandia, Pacific Northwest and the National Renewable Energy

Laboratory to maximize the amount of US-Aid funding directly available for hardware procurement and installation.

Sandia will administer the project planning, specification, and procurement; equipment will be supplied and installed by private industry through an open bid selection process. Approximately $2.5 million of the US-AID funds are expected to be directly invested in the procurement and installation of hardware.

As currently structured, the project will begin in FY94 and will involve close coordination with appropriate Mexican organizations in identifying, selecting and implementing candidate projects having the potential of being highly replicable and demonstrating economically and socially productive uses of commercial renewable energy systems in off-grid applications.

Candidate applications include water pumping for potable supplies, livestock watering, and lower volume irrigation, ice-making and cold storage, and small-scale commercial enterprise power in rural communities supplied by appropriate solar, wind, micro-hydro, or hybrid power systems.

Part of the implementation will be to strengthen the local institutional capabilities in assessing, planning, developing, and sustaining the support of renewable energy projects in Mexico. The selection of projects will be based on factors including their potential for economic and/or social impact, for being replicated at many sites, and for leveraging other funding or program activities. Local institutional interest and support necessary to have the projects be accepted and sustained will also be critical.

Related renewable energy interests and projects are already underway in Mexico, and these projects will work closely with them. For example, an estimated 15,000 photovoltaic systems have been installed in Mexico through other pubicly funded projects. The current effort is effectively an expansion of the US-Mexico renewable energy cooperation program (PROCER), which has been underway since 1991 through Sandia under the sponsorship of the Department of Energy, the Committee on Renewable Energy Commerce and Trade and US-AID Mexico in cooperation with the US Export Council for Renewable Energy and the associated US renewable energy industry associations.

Closure

Sandia National Laboratories is committed to improving the environment through the development of renewable energy technologies. As demonstrated by the above examples, we use technology-specific expertise and the broad range of supporting experimental and analytical capabilities resident at the laboratories to bring innovation both in the technologies addressed and the manner in which they are applied to solving energy problems using environmentally friendly solutions.

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