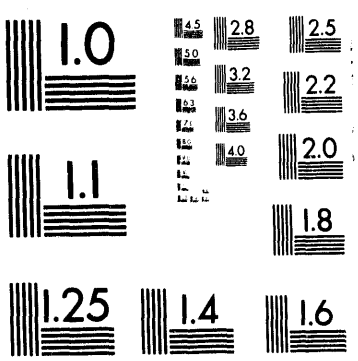
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Renewable Energy Technology Development at Sandia National Laboratories

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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 many of these technologies over the last two decades. This paper describes innovative solar, wind and geothermal energy systems and components that Sandia is helping to bring to the marketplace. A common but special aspect of all of these activities is that they are conducted in partnership with non-federal government entities. A number of these partners are from New Mexico.

Introduction

Sandia National Laboratories supports the U.S. Department of Energy's (DOE) programs in renewable energy by developing photovoltaic, solar thermal, geothermal and wind 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.

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 within the 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. Our photovoltaic technology development efforts emphasize manufacturing innovations that will improve the cost, performance and

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reliability of photovoltaic devices and systems. Our wind energy technologists work with leaders in the U.S. wind energy field to develop component manufacturing processes, product inspection capabilities and system operation procedures that are significantly lowering the costs of energy produced using this familiar renewable natural resource. Significant assistance to the geothermal energy industry is given in the form of advanced drilling technology. In all of these efforts, our technology-specific expertise is combined with the analytical and experimental capabilities of the balance of the laboratories to form a unique resource seen by many as essential to the successful commercialization of these renewable energy systems.

Our non-federal partners include Fortune 500 corporations, small businesses, and state energy offices and departments, and several of these cooperations involve New Mexico entities. Partners include the New Mexico Department of Energy, Minerals and Natural Resources, the New Mexico Solar Industries Association, Plains Electric, and the Public Service Company of New Mexico.

Solar Thermal Energy

Sandia's solar thermal energy technology development efforts look at two basic types of applications: those that produce electricity and those 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 being 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 also work with solar power plant operators. The Kramer Junction Company operates five 30-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. Again, the broad and high technology capabilities of Sandia allow for unique contributions to be made in areas relating to improving the environment and economics for our citizens.

Process Heat

Many of our contributions are not of the very 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 of the correctional facility in Tahachapi, 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. Refrigeration is another area in which 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.

Solar thermal technology is well suited to New Mexico. In addition to Plains Electric, we have ongoing cooperations and discussions with Public Service Company of New Mexico, the New Mexico Department of Energy, Minerals and Natural Resources, the New Mexico Corrections Department and the New Mexico Solar Energy Industries Association.

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 U.S. industry to reduce these costs.

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 U.S. 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. The feedback to industry provided by Sandia's photovoltaic technology development and evaluation activities helps industry improve their 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 multicrytalline 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 U.S. 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 maintained 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.

Wind Energy

Sandia's wind energy technology involvements encompass two levels of effort. By far the most significant in impact has been our utility-scale electric generation RD&T activities. In locations possessing high annual average wind speeds, wind is clearly the least cost option among the emerging renewable technologies in this marketplace, with current bids for supplying electricity at prices as low as 5 cents per kilowatt-hour. Of smaller scope, but having international breadth, is our design assistance for small hybrid systems (e.g., water pumping and village electrification). This paper focuses on only the first type of effort.

Industry Partnerships

The wind program at Sandia has a long history of working with and helping develop commercial wind turbine products. Throughout most of our twenty years of wind energy involvement, we have been working with members of an emerging industry. One of our earliest partnering activities involved the transfer of vertical axis wind turbine (VAWT) technologies to U.S. industry in the early 1980's. This effort led to the installation of over 500 VAWTs in California by the mid-80's, and these turbines are still in successful operation today. This particular relationship has continued over the years in a variety of formal and informal arrangements; its current form is a funds-in agreement whereby the industry partner (FloWind Corporation) has asked Sandia to support the development and testing of an advanced configuration that is intended to replace their existing design. The advanced turbine was installed in early 1994 and is currently undergoing tests that are being supported by our expertise in modal testing and remote data acquisition and analysis.

The above partnership represents a classic example of Sandia's strength in addressing complete systems engineering problems; but our technical depth in specific areas has also often been utilized by U.S. industry. Historically, the single biggest technical problem of the more than 15,000 commercial turbines has been fatigue of their fiberglass blades. Several years ago we initiated a cooperative program with various U.S. blade manufacturers to better characterize the fatigue properties of their blades. That program continues today and has expanded to include problems involved when the fiberglass blade is bonded to a metal connecting hub. In the process of testing both entire blades (in cooperation with the National Renewable Energy Laboratory) and bonded joints, we applied yet another Sandia skill: nondestructive testing (NDT) techniques. Our success in using NDT in the laboratory environment has led to an expression of interest by the industry to apply some of these techniques in the manufacturing environment to assure and improve product quality.

The operation and control of windfarms consisting of hundreds to thousands of units represents an extremely complicated problem. Advances in this area offer the potential to increase energy capture (revenue) while decreasing both regular and replacement O&M costs (through more efficient windfarm operation and management of component fatigue life). We have already entered into a cooperative agreement with the world's largest turbine manufacturer and operator, Kenetech Wind (formerly U.S. Windpower), to attempt to introduce an expert system into their maintenance scheduling process. Beyond this level, numerous other opportunities exist and are being addressed. For example, at the individual turbine level, future controllers may use inexpensive, but powerful, processors to allow such sophisticated operating schemes as fuzzy logic, adaptive learning and individualized performance whereby each turbine is operated to best suit its local environment. At a higher level, windfarm operating strategies can optimize performance of groups of turbines to maximize revenues under the constraint of limited fatigue damage to critical components. In addition, "smart" controllers may be able to predict impending failure and direct preventive actions to avoid costly repairs and degraded availability. Application of wind forecasting techniques may be used to predict performance (thus making wind power outputs look more dispatchable), and, through coupling with the controller, to provide additional increased revenues and decreased maintenance costs.

Geothermal Energy

Electric power production from geothermal resources in the western United States is marginally competitive today with many of the conventional forms of power production. A favorable competitive advantage could be achieved by reducing the cost of drilling exploration, production and injection wells. This is the major focus of Sandia's geothermal program--to reduce drilling costs by working with industry to improve available technology. Another important activity is directed at expanding known geothermal reserves. This work is primarily driven by industry and supported by both federal and state agencies. Additionally, Sandia is working with the DOE and industry to improve market penetration of geothermal heat pumps that can reduce energy use through improved efficiency.

Geothermal Drilling

Geothermal wells account for 35-50% of the total costs of a geothermal project. Through systems analysis and industry reviews, several high-impact project areas have been identified to reduce drilling costs. Included are work in lost circulation control, borehole instrumentation, synthetic diamond drill bits, acoustic data telemetry, and projects of the Geothermal Drilling Organization.

Lost circulation is the loss of drilling fluids to pores or fractures in a wellbore during drilling. This loss of fluids is expensive and causes problems related to hole stability and wellbore completion. Sandia is developing downhole and surface tools, materials, and

techniques to reduce the cost of detecting, diagnosing and treating lost circulation zones. Surface and borehole instruments and borehole packers have been developed. Large scale test facilities are available to evaluate tools and procedures in a controlled environment.

Wellbore measurements are needed to assist drilling decisions, determine reservoir properties, and identify production difficulties. However, typical geothermal reservoir temperatures preclude the use of logging services developed for oil and gas wells. Sandia is working with the geothermal industry to develop a suite of memory logging tools that can obtain the required data at temperatures up to 400 C for reasonable cost. Several new tools are available and are being evaluated by geothermal operators.

Downhole measurements near the bit with data transmission to the surface during drilling operations will play a major role in reducing drilling costs in the future. Savings will result from optimized drilling parameters and "smart drilling" where the well trajectory is modified during drilling based on formation measurements. Sandia has been awarded several patents in this area that will greatly improve the communication channel from the drill bit to the surface by telemetry of data through the drill pipe. Baker Hughes INTEQ has an exclusive license to commercialize this technology.

Sandia, DOE, and industry have established a Geothermal Drilling Organization where short term projects are identified for 50/50 funding by DOE and industry. Projects result in the development of a new product or service that benefits the geothermal drilling industry. Completed projects have developed high-temperature borehole acoustic televiewers, downhole air motors, new elastomers for rotating head seals and drill pipe protectors. On-going projects include corrosion-resistant cements, retrievable whipstocks, and improved drill motors.

Geothermal Exploration

According to resource estimates by the U.S. Geological Survey, geothermal has the potential to contribute 100,000 quads to U.S. energy needs. However, to date, only a small fraction of this resource is proven. Extensive exploration is needed to realize the geothermal potential.

Systems analysis of geothermal development identified drilling costs for exploration and reservoir assessment as the major factor limiting expansion of proven geothermal reserves. In many cases slimhole drilling can reduce exploration costs by 25 to 75%. Slimhole drilling results in bottom bore diameters 4" or less, whereas standard diameters are 8". Sandia is working with the geothermal industry (utilities and geothermal operators) to demonstrate that slimhole drilling is a valid technique to obtain reservoir properties and prove a region for development at greatly reduced cost. Slimhole projects cost-shared with industry on a 50/50 basis have been developed for geothermal resources in California, Nevada, and the Pacific Northwest.

Sandia is leading a deep exploration project in Long Valley caldera, a major active volcanic caldera located near Mammoth Lakes, California. This caldera is typical of several regions of the United States where enormous quantities of thermal energy reside in the crust at drillable depth. This project has included participants from several federal agencies, state of California agencies, national laboratories, universities, and industry. Funding has been provided by DOE (Geothermal and Basic Energy Sciences), and the California Energy Commission.

Geothermal Heat Pumps

Geothermal heat pumps (GHP) have gained international attention as a proven means of energy conservation and demand reduction. However, the high first cost for residential and commercial heating and cooling applications is a major obstacle to market penetration of this technology. Sandia is leading a program to reduce installation costs, increase performance and, thereby, increase the marketability of GHP technology. Participants include DOD installations and research laboratories, utilities, and universities.

Conclusion

Sandia National Laboratories is committed to improving our 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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