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DEVELOPING THE ENERGY RESOURCES FOR A NEW ERA

ALSO:

**Smart Technologies
Revolutionize Drilling Techniques**

**Renewable Energy
Technologies In Mexico**



Sandia
National
Laboratories

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Springing over the head of Sandia National Laboratories researcher Gary Fischer is a new hopping robot developed at Sandia's Intelligent Systems and Robotics Center. The hopper leaps about three feet high on each jump and could travel as far as five miles on a tank of gas. Inspired by the jumping of grasshoppers, hopping robots such as this one may soon give robots unprecedented mobility for exploring other planets, gathering war-fighting intelligence, and assisting police during standoffs or surveillance operations.

ON THE COVER:

Sandia National Laboratories program manager Richard Diver inspects the Dish/Stirling remote power system. The 500-square-foot mirrored dish at Sandia's National Solar Thermal Test Facility represents a milestone in harnessed solar power. The solar dish tracks the sun, focusing its heat onto a receiver, which collects and transfers it to a Stirling heat engine. The engine is a sealed system filled with gas, and as the gas heats and cools, its pressure rises and falls. The change in pressure is controlled to make the pistons inside the engine move, producing mechanical power. The mechanical power in turn drives a generator and makes electricity.

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To request additional copies or to subscribe, contact:

Connie Myers

Marketing Communications Dept.

MS 0129

Sandia National Laboratories

P.O. Box 5800

Albuquerque, NM 87185-0129

Voice: (505) 844-4902

Fax: (505) 844-1392

e-mail: cimyrs@sandia.gov

Sandia Technology Staff:

Laboratory Directed Research & Development Program

Manager: Chuck Meyers, Sandia National Laboratories

Editor: Chris Miller, Sandia National Laboratories

Writing: Katharine Beebe, Technically Write

Design: Douglas Prout, Technically Write

FROM THE *Editor*

Dear Readers:

The rolling blackouts that troubled Californians last winter and their continued threat this summer are stark reminders that energy—its availability, its cost, and its environmental ramifications—will always be a concern. But those concerns go beyond the nuisance of being left without electricity for an hour or having to dig deeper into one's pocket to pay for rising costs. Such issues pose a threat to our national security and solutions must embrace both policy changes and new technologies.

Sandia National Laboratories initiated its energy research program about the time of the 1973 oil embargo and energy crisis. Sandia initially focused its research on solar energy as an alternative clean energy source. While that work continues, we have expanded our research into other areas, including more efficient drilling for fossil fuels, innovative methods to inspect natural gas pipelines, and the development of software programs to more effectively seek out fossil fuel deposits and to handle the complexities of power generation in a distributed network.

This issue of *Sandia Technology* discusses a portion of that work, all of which will ultimately boost our national security.

Chris Miller
Editor



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INSIGHTS

Sandia Helping to Meet America's Need for Clean Energy Resources

by Marjorie L. Tatro
Director, Energy & Transportation Security Center
Sandia National Laboratories





Solar Two power plant near Barstow, Calif.

Our national security and continued prosperity depend in large part on the development of reliable, affordable, clean energy sources. The United States has experienced disruptions to its energy supply, notably during the 1970s when gas and oil supplies dwindled and prices skyrocketed, and more recently this past winter when rolling blackouts struck California.

As the United States continues to formulate a national energy policy that addresses such things as harvesting domestic energy resources, import and inventory needs, drilling policies, and conservation strategies, individual states have enacted legislation that affects energy supply and pricing for local utility companies. Meanwhile, our scientists and engineers are developing technologies to enhance energy supplies and efficiency in concert with private industry, universities, and utility companies. The Department of Energy and U.S. industry

Developing **THE ENERGY RESOURCES** *of A New Era*

sponsor these development activities.

Sandia has been helping to develop solutions to ensure the stability of our energy supplies since the 1970s. The challenge is multifaceted and much of the effort now is focused on developing distributed, decentralized energy networks. That represents a shift from large centralized power plants to smaller, often higher-efficiency plants located at the point of

consumption. But such a shift poses new challenges that include their interconnection and their ability to communicate securely to ensure there will be no disruptions, whether accidental or intentional, in the supply of energy to consumers. Sandia also is helping to develop improved tools and techniques that potentially could revolutionize drilling operations for the oil, gas, and geothermal industries.

SMART TECHNOLOGIES

Revolutionize Drilling Techniques

America's ever increasing demand for energy is creating a need for additional gas, oil, and geothermal resources. But the more resources we extract from the earth, the more difficult it becomes to reach those that remain. Drillers are forced to go deeper, causing costs to rise. A typical geothermal well costs between \$2 million and \$3 million to drill. An oil or gas well can cost tens of millions of dollars to drill.

Sandia is developing technologies that make drilling more efficient, and therefore, less costly.

The driller, hard hat and coveralls splashed with mud and grease, stands before his console on the rig floor and watches the drill string turn. Two miles below at the other end of the spinning string of pipe, the bit chews away at a hot, hard layer of rock that lies above the pay zone. Operating such a rig is expensive—costing anywhere from \$15,000 a day for a small land rig to more than \$250,000 a day for an offshore rig. The potential pitfalls



Drilling for oil.

Quick, reliable communications from downhole to the surface could revolutionize the drilling process.

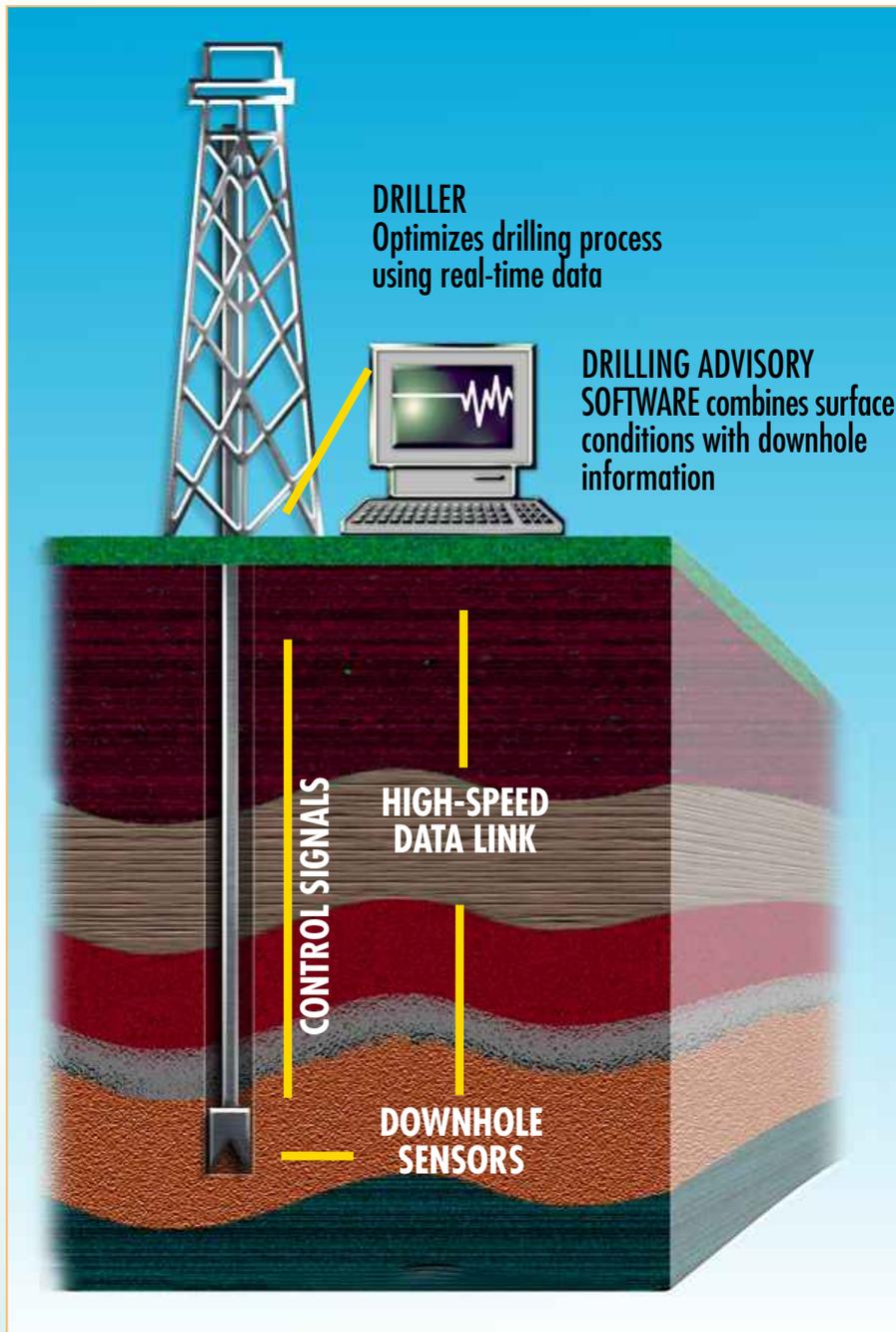
the rig can run into are many. For instance, the bit can wear out quickly, causing its operator to spend hours pulling thousands of feet of drill pipe out of the hole to install a new bit. The drill string can twist, or it can cause the drill assembly to get stuck in the hole—two possible situations that the driller may be able to avert if better

information is available from downhole. Incomplete information from downhole also can lead to equipment failures and procedural mistakes that allow oil, gas, or steam to flow uncontrollably up the wellbore.

Drillers have few options in conventional drilling operations. The driller can only control weight-on-bit (the force that drives the bit into the rock), the rotary speed of the drill string, and the flow rate of drilling mud (the viscous liquid that circulates down the drill pipe through nozzles in the bit and back up the hole, carrying the drilled chunks of rock with it). The long, slender drill pipe gives the operator little hint of what may be happening downhole. Is the bit bouncing off the bottom, breaking its teeth and soon to become unusable? Has the temperature of the rock suddenly

risen? Has the bit penetrated a pocket of high-pressure fluid, causing the well to flood? Even in trouble-free drilling, with the driller simply trying to optimize performance by changing weight-on-bit or rotary speed, it may be a few minutes to an hour before he can assess the effect of a change. Quick, reliable communications from downhole to the surface could revolutionize the drilling process.

This is not a new idea. Efforts to improve this communication began more than half a century ago. For the past 20 years, a rudimentary technology called measurement-while-drilling (MWD) has helped get the measured data to the surface. MWD today is used



Sandia's Diagnostics-While-Drilling System.

primarily to control the path of wells. Data are transmitted via pressure pulses in the stream of mud that circulates in the well. But the information travels relatively slowly, almost always under 10 bits per second (baud), compared with common computer modems, which transfer data at 57,000 baud. While MWD systems are used widely on expensive offshore operations, they are not used very

often on inexpensive onshore operations such as geothermal drilling. This technology also fails under high temperatures.

Sandia's Geothermal Research Department is developing a new technology, diagnostics-while-drilling (DWD). DWD will use a data loop, which will bring high-speed, real-time data up the hole, combine it with measurements made at the surface,

DWD's potential ability to anticipate problems promises to greatly reduce "flat time," the industry term for the time the rig is in use, costing the rental rate, but not advancing the hole.

integrate and analyze these measurements to advise the driller, and then return signals downhole for control of smart tools.

Sensors near the bit will measure such things as pressure and temperature, and will show whether the bit is turning smoothly. All signals will be sent uphole quickly. If the DWD concept proves workable, the driller will know immediately when problems arise, in time to take corrective action. He will know when the bit drills into a new kind of rock or, in many cases, even when it is about to fail. This year, Sandia also will test a prototype DWD system with synthetic diamond (PDC) bits to drill hard rock.

The system will send bit-performance data to the surface at almost 200,000 baud, giving enough knowledge and control to use this improved bit in the kind of rock typical of geothermal reservoirs.

DWD's ability to anticipate problems should greatly reduce "flat time," the industry term for the time the rig is in use, costing the rental rate, but not advancing the hole.

For more than two decades, Sandians have been working to cut the costs of geothermal well drilling and completion. Today, such R&D programs support the government's goal to see 10 percent of the electrical power in the western United States generated by geothermal energy by 2020.

Sandia works closely with industry to achieve that goal, including holding quarterly meetings with



industry advisors. “We’re very conscious of the need for industry feedback on the DWD concept. We want to ensure that we are trying to solve relevant problems and are doing so in an appropriate way, so we aim to maintain open lines of communication around our research developments,” said DWD project leader John Finger.

Acoustic telemetry shows promise

Because it will employ a wire in the well, DWD is not practical for everyday drilling applications. Other R&D programs in the Geothermal Research Department will help the effort. Acoustic telemetry, which doesn’t use a wire, provides a possible alternative. A method of sending a signal through stress waves that travel up the steel of the drill string, acoustic telemetry will provide information at a much broader bandwidth than mud-pulse telemetry.

Researchers at Sandia’s Orpheus test site operate a typical well pipe—1,400 feet long but scarcely a handspan in diameter. They are experimenting with continuous tones generated by a transmitter at one end of the pipe, and identifying the frequencies that can successfully travel its length.

The downhole acoustic transmitter is designed to translate data needed by the driller into a waveform. Sandia’s prototype displays the electronically

amplified waveform on an oscilloscope housed in a nearby trailer.

Baker Hughes, one of three leading oil field service companies, has been interested enough in the system to buy a nonexclusive license for the technology, as has Passband Downhole Communication, a Canadian venture capital firm. Sandia project manager Douglas Drumheller says mud-pulse telemetry has been a useful tool, but more and more often it is failing to do the job. “Something more is needed, and that’s why acoustic telemetry technology is so promising. Acoustic telemetry works when mud-pulse works. It also works when the mud isn’t circulating, and the rate at which it sends data is at least one order of magnitude faster than mud-pulse signals.”

Comparing mud-pulse telemetry to acoustic telemetry is like comparing the telegraph to the telephone: because mud-pulse components are mechanical, the data rate is thousands of times slower than the slowest computer modem, causing information bottlenecks. In acoustic telemetry, the signal is transmitted electronically by stress waves in the drill string. The system’s repeater, an intelligent device that receives and decodes the message and then constructs and broadcasts another message, will give the acoustic communications an unlimited range capability with power from D cell flashlight batteries. The communication range of Sandia’s primary transmitter is guaranteed to operate up to 10,000 feet, but the technology can sometimes penetrate more than 15,000 feet.

Until now, acoustic telemetry has not been implemented successfully because of the complexity of the physics involved in system design. To overcome these barriers, the Sandia team has focused its work on four aspects of acoustic telemetry: building simple, robust transmitters; determining the communication range; trying to understand the effects of well noise; and designing an optimum repeater.

Sandia also wants to help private industry develop high-temperature tools that can withstand the increasingly higher temperatures that drillers encounter as they dig deeper. Hard, hot, fractured rocks reduce the life span of bits and electronic tools to about eight hours.

Drumheller said Sandia is attempting to make acoustic telemetry simple to use. “Our aim is to demystify the system so that it is easy to obtain the data necessary to make intelligent drilling choices. We want to design a black box that drillers simply slap on the end of the drill string, run down-hole, and listen to, while the underlying technology remains transparent.”

Another promising way of getting signals uphole is transmitting them over an optical fiber. Optical fiber is commonly used in drilling operations because optical signals have essentially unlimited bandwidth, allowing for enormous data-carrying capacity. Sandia is experimenting with ways to use optical fiber simply and more cost-effectively. In partnership with the Gas Technology Institute, Sandia is developing a system for deploying an unarmored optical fiber inside drill pipe to serve as a data link. After drilling, the fiber is disposed of easily and inexpensively. Future R&D funded by the DOE will apply the same approach to operations in which coil tubing replaces the drill string for greater flexibility.

High-temperature tools

Sandia also wants to help private industry develop tools that can withstand the increasingly higher temperatures that drillers encounter as they dig deeper. Hard, hot, fractured rocks



Since the 1970s, synthetic polycrystalline diamond compact bits have provided more efficient drilling bits. Sandia is applying knowledge gained from radiation hardening to the development of new drill-bit technology.

reduce the life span of bits and electronic tools to about eight hours and make conventional instruments complicated to use. About 50 percent of conventional electronics fail at 150° C, and of the remaining 50 percent, 80 percent fail before reaching 200° C.

“A huge need exists for high-temperature electronics and sensors on drilling operations, and yet the relatively small market for geothermal energy gives equipment manufacturers little incentive to produce tools,” said principal investigator Randy Normann. “Geothermal well-bore instruments are almost nonexistent, and those that are available have a high price tag.”

The Department of Energy’s Office of Energy Efficiency and Renewable Energy has asked Sandia to develop high-temperature instruments for drilling and logging (measuring) geothermal wells. In response, Sandia is developing a variety of components for use in a suite of tools. “Our target temperature is 300° C, which is hot enough to cover 90 percent of the geothermal wells within the United States,” Normann

said. Most common well logging and well-bore measurements are performed using a custom application-specific integrated circuit with silicon-on-insulator (SOI) technology. SOI technology provides a means of hardening silicon electronic components to perform in extremely high temperatures, similar to the way electronic components are hardened to withstand radiation. Recently, working with Honeywell’s Solid State Electronics Center, Sandia developed and demonstrated the industry’s first 300° C microprocessor-based circuit, a device that ran for more than 200 hours through several temperature cycles. Sandia’s SOI prototypes have already been tested successfully at temperatures above 250° C.

High-temperature electronics have potential applications in other industries. For instance, this technology could be used in commercial aircraft to move control circuits out of the cockpit and into the engines, substantially reducing the number of wires running across the aircraft. This would increase reliability, yet reduce payload by about 600 pounds.

Sandia’s Geothermal Research Department is working on other important aspects of drilling, such as improving high-performance drill bits, refining ways to monitor mud flow, and developing better instrumentation for the rig’s surface equipment. All of these contribute to reducing the cost of drilling geothermal wells.

Sandia currently holds seven patents on downhole acoustic transmitter designs. In addition, the labs has a patent for improving the ability of the drill string to carry signals, and has filed for a patent associated with the design of a repeater. Sandia also has four copyrights on related computer software programs. Sandia is protecting other commercially valuable information as trade secrets to be given to future commercial licensees of its acoustic telemetry technology.

TECHNICAL CONTACTS:

John Finger
505-844-8089
jtfinge@sandia.gov

Douglas Drumheller
505-844-8920
dsdrumh@sandia.gov

Randy Normann
505-845-9675
ranorma@sandia.gov

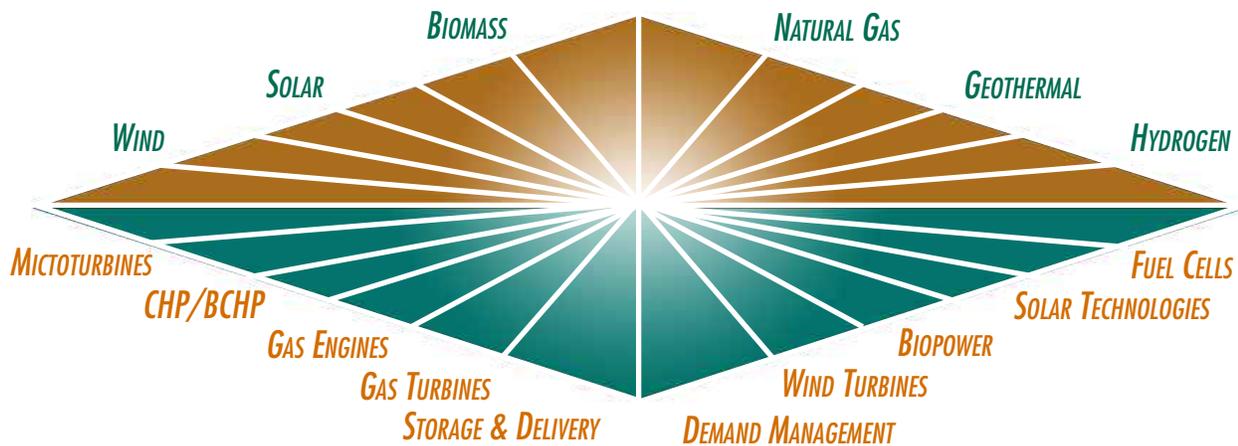
David Holcomb (optical fiber)
djhholco@sandia.gov
505-844-2157



SMALLER ENERGY SYSTEMS

*To Play Macro Role In Developing
Future Energy Resources*

Increased energy efficiency. Enhanced electric grid operations. Greater reliability. Stronger local economies. Reduced pollution and greenhouse gas emissions.



Realizing the ambitious energy goals listed above is vital to achieving a sustainable high quality of life for Americans over the next two decades. And obtaining the goals ultimately are necessary to maintain our national security. An emerging and promising trend for realizing our future energy needs is a shift from large centralized power plants to smaller, often higher-efficiency plants located at the point of consumption. Called distributed energy resources (DER), these smaller energy resources can include solar photovoltaics (PV), solar thermal systems, fuel cells, micro-wind turbines, and small micro-gas-fired turbines. Storage technologies such as batteries will also play an important role in a more distributed energy network.

The challenge is how to integrate these next-generation technologies into our nation's power grids. The smaller

units must be adequately controlled and monitored, and communication between them must be appropriately secure.

Multiple Technologies Interconnections

At its Photovoltaic Systems Evaluation Laboratory, Sandia is testing a 75 kW Honeywell microturbine for Laguna Pueblo, located 40 miles west of Albuquerque. The tests give Sandia an opportunity to evaluate a new distributed-generation system in several modes of operation, including how successfully it will operate with other energy sources.

This activity is partially sponsored by Sandia's New Mexico Small Business Technical Assistance Program. Knowledge gained from the Laguna project will help the Department of

Energy achieve its vision for the year 2020: the United States as a showcase for the most efficient, most reliable, and cleanest energy in the world, through the optimization of distributed energy resources. The DOE forecasts that distributed energy resources such as the Honeywell turbine will contribute 20 percent of the nation's new power generation capacity.

Intelligent Agents

The integration of intelligent agents—software programs capable of handling the complexities of power generation in a distributed network—into an energy grid may help to avert power catastrophes such as the cascading power failures that paralyzed much of the western United States in 1996. The agent is able to identify problems as they



SCADA monitors wind turbines in Bushland, Texas.

occur and to keep a power system operating when raw data are not available because the connection with the substation has been interrupted, said Sandian Laurence Phillips. Phillips said intelligent agents also could help detect and prevent the introduction of corrupted information into the system. “We are designing security into the agents from the ground up,” he said. “The agents’ ability to quickly make decisions would also be helpful in managing deregulated power grids.”

Please see Dish/Stirling article on page 13 for more details.

Secure Remote Monitoring and Control

Sandia is developing specifications for more secure control systems for distributed energy resources. Called SCADA, for supervisory control and data acquisition, the systems are used in many industries and are important for monitoring and controlling equipment on electric power systems. In a distributed energy network with a large number of energy generation and storage devices to control, the reliability and security of SCADA systems become more critical than in today’s network.

Sandia’s SCADA researchers serve as advisors to national and international standards committees charged with developing security specifications for future SCADA systems.

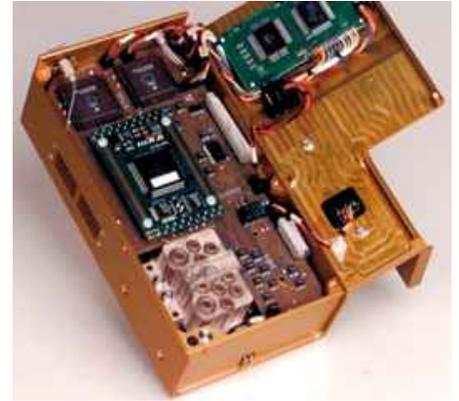
New information architectures and security features for SCADA systems are being tested in Sandia’s SCADA test lab. The lab includes communication and control ties to DER and information research facilities. Wind turbines in Texas, Dish/Stirling engines located five miles away, photovoltaic arrays, and battery banks located at a nearby building are tied into the SCADA test lab. Information research facilities, including a data-visualization lab, a cryptographic research lab, and an information system security assessment lab, are also connected to the SCADA test lab. Universities, utilities, equipment manufacturers and vendors are invited to use the test lab to assess the robustness of new control system designs and SCADA features.

Please see Dish/Stirling article on page 13 for more details.

Microsensors

As smaller, smarter sensors are developed, they likely will be integrated into utility systems to improve production and transmission efficiencies, enhance environmental performance, and reduce cost. Sandia and the Electric Power Research Institute (EPRI), a nonprofit organization that seeks technology-based solutions for the electric utility industry, are jointly exploring potential applications of Sandia’s μ ChemLab™, and microsensors technologies for the utility industry. EPRI and Sandia plan to develop new chemical microsystems to address emerging environmental issues that confront the utility industry. An initial goal is development of a new class of microsensor that can better identify PCBs or other environmental contaminants in air and water.

Utility companies are being invited to prioritize their needs in sensor technologies and to join the team, creating the kind of proactive



Technology used in Sandia’s μ ChemLab™ could be useful to the utility industry.

partnership that the DOE has called for to develop the nation’s distributed energy resources. Using Sandia’s extensive expertise in microsensors and μ ChemLab™ technology as a basis, the R&D team will develop the appropriate microsystem for various target applications.

TECHNICAL CONTACTS:
Al Sylwester (microsensors)
 505-844-8151
apsylwe@sandia.gov

Steven Goldsmith (intelligent agents only)
 507-292-1425
sygolds@sandia.gov

Islands in the Energy Stream

Ensuring Power-Flow Safety



New photovoltaic control method allows easier and safer use of alternate energy sources on the electric grid.

The scenario is all too common: a power line is down and the utility company has been alerted. Line workers ensure their safety and the safety of passersby by shutting off power from the grid—a routine procedure to ensure a de-energized line.

But in an era of distributed energy, a utility company may not have full control over shutting off power. For instance, if a homeowner or business has a photovoltaic system tied to the electric grid and it isn't shut off—a situation called islanding—energy can still flow into the system, possibly endangering both people and equipment.

Following the overhauled standards and using the new techniques, inverter designers and PV system engineers now, for the first time, work from a common plan.

Sandia has initiated a test program to explore the conditions under which islanding occurs. Sandia researchers also have made some interesting discoveries during product tests. For instance, a Sandia team found that the islanding protection features of some

inverters actually interfered with the islanding protection features of other inverters, creating the very situation they had been designed to avoid. Sandia tests also found that the individual inverters were not responding quickly enough.

In cooperation with many photovoltaic inverter manufacturers, Sandia developed a technique that could be incorporated into any inverter to ensure islanding won't occur.

Sandia engineers have been able to define the characteristics of a non-islanding inverter and to establish a new procedure to distinguish between inverters that have satisfactory anti-islanding techniques and those that

don't. The procedure has been adopted by Underwriters Laboratories (UL) as a part of its standard for photovoltaic converters, and has been incorporated into the IEEE (Institute of Electrical and Electronics Engineers) standards.

Through innovative modifications to inverter controls, Sandia has developed techniques for identifying and manufacturing an inverter that meets the new requirements. Following the overhauled standards and using the new techniques, inverter designers and PV system engineers now, for the first time, work from a common plan.

All UL-listed inverters manufactured after November 2000 must meet standards for automatically diverting or turning off electricity flow from grid-connected PV systems when an electric distribution line shuts down. Standardization has benefited the utility, the installer, and the buyer by providing components that are built and tested to a standard. The probability of defective hardware is reduced, and cost savings are encouraged. And the

Standardization has benefited the utility, the installer, and the buyer by providing components that are built and tested to a standard.

standard does not apply solely to PV systems. The standardized single inverter design and the new standards may be applied to other renewable energies, said project manager John Stevens. "One of the contributions this R&D program has made to the distributed energies field is the universality of its findings. Because the PV array itself was not a factor in our development of the anti-islanding techniques, the energy source can potentially be any of a number of devices including batteries or fuel cells," Stevens said. "Also, the best response of an inverter upon detection

of an island condition may not always be to shut down. In a scenario where there is sufficient distributed energy resource to keep critical loads active, the best response may be to switch from utility-tied mode to stand-alone mode so that critical loads can remain functional."

Sandia's R&D program for single and multiple inverter evaluations continues. The new goals, Stevens said, are to expand the knowledge base and to extend the single-inverter test to new inverter models.

TECHNICAL CONTACTS:

John Stevens
505-844-7717
jwsteve@sandia.gov

Joe R. Tillerson,
505-844-1806
jrtille@sandia.gov



Photovoltaic-covered parking structure at the offices of the South Coast Air Quality Management District in Diamond Bar, California (a Los Angeles suburb). The PV is tied into the grid and powers the office building. Employees who drive electric vehicles to work are allowed to park under the shade of the PV panels and use the energy to charge their car batteries while at work.

Dish/Stirling

Provides Test for Secure Control System



Program manager Richard Diver inspects the Dish/Stirling remote power system.

The 500-square-foot mirrored dish at Sandia's National Solar Thermal Test Facility represents a milestone in harnessed solar power. As the dish tracks the sun, it focuses its rays onto a receiver, which collects and transfers it to a Stirling heat engine. The engine is a sealed system filled with gas, and as the gas heats and cools, its pressure rises and falls. The change in pressure is

A key to the success of the Dish/Stirling is its supervisory control and data acquisition capability, which allows it to be controlled and monitored from a distance.

controlled to make the pistons inside the engine move, producing mechanical power. The mechanical power in turn drives a generator and makes electricity.

Key to the success of the Dish/Stirling system is its supervisory control and data acquisition (SCADA) capability, which allows it to be controlled and monitored from a distance. A research team remotely controls the dish's angles, motor speed, and other operational details. The



Sandia's Red Team conducts a systems vulnerability analysis of the supervisory control and data acquisition system (SCADA) by trying to break through its security system.

Dish/Stirling's 10 kW generator and its overall architecture reflect on a small scale the direction in which the renewable energies industry is headed. The lessons learned from Dish/Stirling, particularly in developing a secure SCADA system, eventually will be applied industrywide, said Rolf Carlson, a principal investigator for high surety SCADA research at Sandia.

"Sandia's reliability and security R&D focuses on real-time responses to unforeseen events. Our goal is to develop the capability to keep the power on, even under adverse circumstances," Carlson said.

The utility industry has not always faced security concerns. Prior to deregulation and the advent of smaller utility systems, utilities had their own proprietary systems, each one offering a modicum of security. Today, the migration toward open systems and networking has led to the creation of industry standards and made shared protocols a necessity.

"Faced with deregulation and the need to move information quickly and seamlessly across company environ-

ments, the utility companies are having to determine what information to share and how to protect it," explained Juan Torres, a principal investigator on distributed energy resources projects. "The systems now being brought online by the utilities must incorporate security features. Sandia's work in security and sensor technologies is part of that evolution towards secure systems—we are weaving security deeper and deeper into the distributed energy control systems environment."

Sandia's SCADA technology draws upon its vast experience in energy systems and information system security. The goal is to develop economical, highly secure, robust solutions.

Sandia is incorporating authentication and cryptographic protocols, centralized or decentralized control, firewalls, and other features into its SCADA systems. Much of this work stems from its partnerships with companies like MCI Worldcom, Cisco, Raytheon, and Quetana Systems.

Sandia's SCADA technology draws upon its vast experience in energy systems and information system security. The goal is to develop economical, highly secure, robust solutions.

Once the security enhancements are in place, Sandia's "Red Team" conducts a systems vulnerability analysis by trying to break through the security system. The team analyzes both design methodology and the efficacy of equipment. "What the energy industry needs is a unified control architecture for critical infrastructures," said Torres. "A number of open protocols exist but they were not being put together in a secure way."

Sandia is taking a proactive role in facilitating the design of total system security for the next generation of SCADA by partnering for technology development, by helping users to implement their systems, by participating on standards committees, and by cooperating with vendors who are generating the security markets.

TECHNICAL CONTACTS:

Rich Diver (Dish/Stirling)
505-844-0195
rbdiver@sandia.gov

Juan Torres (SCADA)
505-844-0809
jjtorre@sandia.gov

Sandia Program Promotes Renewable Energy Technologies In **Mexico**

On Mexico's Yucatán Peninsula, a submersible pump powered by photovoltaics yields enough water to maintain a herd of cattle on a farmer's small ranch. Hundreds of miles away, in the peninsular desert of Baja California, water automatically flows into cattle troughs and drip-irrigates a crop. Here, too, the power is provided by a new photovoltaic (PV) water-pumping system.



Agua Blanca, Baja California Sur—Rancher Marcos Alvarez creates agricultural abundance with his new photovoltaic water-pumping system, installed with technical and funding assistance from Sandia.

These are just two of the approximately 250 PV and wind-energy water pumping systems, provided by Sandia's Mexico Renewable Energy Program, that are improving the lives of thousands of Mexican people living in rural areas.

"To really comprehend the world of good these innovations accomplish, you have to see the effect this technology has on the lives of people who probably haven't had electricity in their lifetimes," said Michael Ross, program manager for Sandia's Mexico Renewable Energy Program. More than 15 million people in 100,000 Mexican rural communities are in need of potable water processing capabilities, and at least 600,000 ranches need water for livestock and irrigation, he said.

"To really comprehend the world of good these innovations accomplish, you have to see the effect this technology has on the lives of people who probably haven't had electricity in their lifetimes."

The Mexico Renewable Energy Program improves the economies of some of the poorest areas of rural Mexico. Wind and solar energy increases the profitability of small ranches, reduces pollution from traditional fuel-powered generators, and

broadens the renewable energy market outside the United States.

Sandia's work in Mexico began in the early 1990s under the sponsorship of the U.S. Department of Energy's National Photovoltaics Program and the Committee on Renewable Energy, Commerce and Trade. The Program is currently cosponsored by the DOE's Office of Solar Technologies and the Mexico mission office of the U.S. Agency for International Development (USAID).

More than fifty U.S. and Mexican suppliers have worked with Sandia in renewable energy projects since 1994, when Sandia established its Mexico Renewable Energy Program. More than 400 renewable energy pilot systems have been installed in 14 Mexican states under the program, producing more than 270 kilowatts of clean, renewable power that is directly benefiting about 29,000 Mexicans living in rural areas. The program boosts U.S. job creation and sales since most of the system components are manufactured in the United States.

In addition to aiding Mexican farmers, the program supports community water supply and disinfection, telecommunications, small community electrification, solar home systems, and monitoring stations. The program



The goal of Sandia's Mexico Renewable Energy Program is to make the use of renewable energy systems in Mexico widespread and self-sustaining. Energy availability is a key element of security for any nation, including Mexico, said Marjorie Tatro, director of Sandia's Energy and Transportation Security Center. And that ultimately will benefit the United States, she added.

TECHNICAL CONTACT:

Michael Ross
505-844-3301
mpross@sandia.gov

Mexican engineers discuss the recent installation of a photovoltaic water-pumping station on Rancho Sagitario in Baja California Sur, just outside of La Paz.

enhances U.S. national security because it helps to stabilize the flow of rural migration to Mexico's urban areas and into the United States.

One of the leading partnerships is the Renewable Energy for Agriculture Program managed by Mexico's Fideicomiso de Riesgo Compartido (FIRCO), an agricultural extension service under the Mexican Ministry of Agriculture. FIRCO plans to bring 1,200 new PV systems and 55 wind systems to isolated areas of Mexico over a five-year period. The systems will be used for such things as pumping water and creating electricity for refrigeration.

Sandia's expertise and involvement goes beyond design and development of renewable-energy systems. Engineers help write system specifications and they frequently help install the systems and teach local organizations, users, and vendors how to install, operate, and maintain the systems.

Sandia also helps Mexican ranchers find financing for the systems. When used in productive applications such

as water pumping, the systems pay for themselves relatively quickly compared to other conventional energy generators, Ross said.



Sandia National Laboratories renewable energy expert Michael Ross works on a photovoltaic water-pumping system at a ranch near Cancún on Mexico's Yucatán peninsula.

Safety Innovations In THE PIPELINE

In the wake of a natural gas explosion that killed 12 family members last August at a Carlsbad, N.M., campground, renewed attention has focused on how to

The issues raised by the explosion were not new. The nation's natural gas pipeline system is relatively safe, but concerned by its aging infrastructure, the U.S. General Accounting Office (GAO) had recently reassessed safety statistics, pipeline reliability issues, and inspection jurisdictions. The GAO issued a report in June 2000 that called for stricter regulations. Scarcely was the report off the press when the explosion occurred, giving the priorities new impetus.

Sen. Jeff Bingaman, D-N.M., turned to Sandia for recommendations on applying new technologies to solve these problems. The labs issued a white paper titled "Capabilities and Areas of Research and Development to Enhance Pipeline Safety in the U.S." Compiled by Dan Horschel and several other Sandians, the paper outlined current R&D at Sandia that could be applied to support improved



Mobile robot technology is one area of expertise that could be applied to safety problems in natural gas pipelines.

safety measures in the natural gas distribution industry. The paper also identified a number of areas where Sandia could work with industry to tackle the challenge.

Horschel emphasized that Sandia doesn't have all the answers. "But there is some overlap between the safety issues and areas where Sandia technology might help. We want the best that technology can offer to be available to the gas industry as it looks for ways to improve safety," he said.

make the nation's millions of miles of gas pipeline safer. The explosion ruptured a gas pipeline, leaving a 20-foot deep crater on the banks of the Pecos River.

Sandia has worked on the safety and reliability of the nation's gas distribution system for the past five years. Sandia's Critical Infrastructure Protection team had studied gas pipeline performance and had developed several technologies that could be used to improve safety.

Better Sensors. Sandia sensor innovations can be adapted to produce "super sniffers" to detect pipeline leaks more quickly. Current R&D projects offer an array of possibilities including the following:

- μ ChemLab™, a battery-powered sensor system weighing less than three pounds, is bringing detection and analysis capabilities into the field. Now in testing, the portable micro-gas chromatograph can be used to identify a natural gas leak of minute concentrations.

- **Surface acoustic wave (SAW) sensors** detect leaks by trapping gas particles in a thin chemical film, then identifying the trapped gas species with acoustic signals.
- **Chemically coated fiber optics** offer yet another innovation. A beam of light transmitted down a fiber optic line reflects differently when the chemically selective coating on the line's pinpoint end has absorbed a gas. Sandia developed the fiber optics approach to detect jet fuel leaks from storage tanks.
- **Field-effect transistor (FET) sensors** that detect dangerous hydrogen leaks in rocket boosters could be modified to detect pipeline leaks. The sensors could be integrated at relatively low cost into a dime-sized package.

Gas Imaging. The presence of trace gas leaks can be a harbinger of catastrophic gas pipeline failure. Sandia is developing a new technology—laser-illuminated infrared imaging—which makes gas leaks visible in real-time video. Using a laser light, the imager depicts a wavelength tailored to the gas being sought. If the gas is present, it will absorb the light, creating a shadow in the video image. The technique promises to increase the speed and efficiency of gas-leak surveying. Van-mounted imagers have been successfully tested in the Atlanta, Ga., gas-distribution system and at petroleum refineries in Houston, Texas. A handheld battery-operated imager similar to a camcorder is being developed for application in industrial settings. Currently, low concentrations of gas can be detected up to 60 feet away. Researchers believe system sensitivity can be enhanced to permit detection underground or from the air.

Robotics. The gas industry uses “smart pigs,” or sensor-laden “logs,” to detect structural flaws or deformations inside pipe. The information the pigs provide is often limited and they are unable to pass through small pipes, tight turns, and many valves. Sandia is drawing upon its

Predicting future failures based on statistics describing past failures, called probabilistic risk assessment, is not new at Sandia. Sandians have been honing these skills for years as part of the labs' mission to keep U.S. nuclear weapons and nuclear power plants safe and reliable.

robotics and sensor expertise to investigate the feasibility of producing a “smart piglet,” a device smaller and more agile than a pig and capable of storing image data that would allow the pipe's interior to be mapped.

Supervisory Control and Data Acquisition (SCADA). The natural gas grid relies on SCADA controls to monitor and control gas flow in gas lines. A well-instrumented, intelligent and secure SCADA system could detect small pressure drops—signaling a leak in the pipeline—that would minimize false alarms and enable rapid or automatic shutdown of leaking gas lines. Sandia's ongoing program to improve the security and reliability of SCADA could help ensure the timeliness, accuracy, and authenticity of data and control signals in future gas transmission systems.

Remote Field Eddy Current Devices. Eddy current devices similar to the type used to find flaws in aircraft structures could be adapted to detect cracks and corrosion in gas pipelines.

Probabilistic Risk Capabilities. Predicting future failures based on statistics describing past failures, called *probabilistic risk assessment*, is not new at Sandia. Sandians have been honing these skills for years as part of the labs' mission to keep U.S. nuclear weapons

and nuclear power plants safe and reliable. They have expanded their applications to space vehicles, aircraft, and the nation's telecommunications and electrical power grid systems. Similar assessment techniques incorporated into industry-specific software tools could support the development of improved inspection and maintenance strategies, including optimal replacement systems. They also can be used to pinpoint pipe sections most prone to failure, eliminating costly and often ineffective hit-or-miss approaches.

Last September the U.S. Senate passed a bill that included an amendment cosponsored by Sen. Bingaman to require pipeline inspections every five years. However, the bill did not make it out of the U.S. House of Representatives. This year, Sen. John McCain, R-Ariz., has introduced a new bill that includes Bingaman's R&D provision in its entirety. It was slightly redrafted from the stand-alone bill to fit the structure of the McCain bill, which would direct the Department of Transportation to issue regulations requiring pipeline operators to periodically determine the adequacy of their lines.

“As the Carlsbad explosion makes all too clear, catastrophic failures of our systems can have immediate and tragic consequences. We look forward to helping regulators and the pipeline industry by developing and applying technologies that enhance the safety of this critical infrastructure,” said Bob Eagan, Sandia's Vice President of Energy, Information, and Infrastructure Surety.

TECHNICAL CONTACT:
Daniel Horschel
505-845-9836
dshorsc@sandia.gov

INSIGHTS

by *Marjorie L. Tatro*

*Director, Energy & Transportation Security Center
Sandia National Laboratories*



Marjorie L. Tatro

Sandia Helping to Meet America's Need for Clean Energy Resources

Energy reliability is vital to the health of the United States' economy and national security. However, as America grows so do our needs. Consequently, we are overstressing our energy production, supply, and delivery systems. In addition, we are using some systems, such as the electric-power system, in ways for which they were never designed. For example, when originally built, the U.S. electric transmission system carried power from central generation plants to surrounding areas and a single entity, usually an investor-owned utility, managed the systems. Now those systems are additionally tasked to transport power across several states when shortages occur. Complicating matters further, the systems are now owned by many different entities that must coordinate their operations. As a

result, these systems are becoming more complicated and less reliable.

The world's appetite for clean, inexpensive energy, particularly electricity, is increasing. But each fuel supply presents a set of technological challenges. Coal and petroleum supplies are limited and, when burned, generate pollutants that must be minimized. In the next decade, I believe that the use of "carbon currency" (the trading of carbon emissions and carbon offsets as a means of commerce) will become more widespread as the world adopts a set of rules that could help curb the causes of climate change. Measuring carbon emissions of various processes, extracting carbon, and sequestering or recycling carbon will all create the need for new technologies and processes.

Natural gas is a clean-burning domestic resource, but it is distributed via an aging and fragile transmission and distribution network. The increased use of natural gas for electricity production is putting increased stress on this already fragile infrastructure.

We must make further advances in exploration and production technology to enable domestic supplies at reasonable costs. Nuclear fuels and waste products must be stored and transported safely. Renewable sources are currently more expensive and less reliable than other electric generation systems. Increased energy efficiency through improved combustion, waste heat recovery, and simple conservation techniques offer opportunities to use domestic energy supplies more wisely. But these improvements will not be

fully implemented until the price of energy begins to cause economic hardship among consumers.

Finally, electricity restructuring is forcing us to change the way we think about the generation, transmission, and distribution of electricity. The major trend in this area is the use of distributed power sources instead of large central station plants. Distributed power creates opportunities as well as challenges for generation, storage, and control technologies. Meeting these challenges requires technological innovation in a world of complex economic and political variables.

For more than 50 years, Sandia National Laboratories has been helping our nation secure a peaceful and free world through technology. Since the energy crisis of the mid-1970s Sandia has been cooperating with private industry and universities to improve energy technology to bolster America's energy self-sufficiency. We believe a balanced portfolio of energy-supply options that includes nuclear, oil, gas, coal, hydroelectric, solar, wind, geothermal, and biomass power is required to fuel the economic growth of the world.



“Since the energy crisis of the mid-1970s Sandia has been cooperating with private industry and universities to improve energy technology to bolster America’s energy self-sufficiency.”

Marjorie L. Tatro
Director, Energy & Transportation Security Center
Sandia National Laboratories



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