Geothermal technologies
U.S. Department of Energy

Vol. 7 Issue 3
September 2002

SPECIAL ISSUE!

A Description of Current Geothermal Projects in FY 2002

Research and Development

The U.S. Department of Energy (DOE) Geothermal Technologies Program is committed to supporting the geothermal industry with research and development (R&D) to reduce costs and risks, and help geothermal energy fulfill its potential.

The U.S. Geological Survey estimates that the potential of this clean energy amounts to 50,000 times the energy of all oil and gas resources in the world. Although today's geothermal industry is a $1.5-billion-dollar-per-year enterprise involving nearly 3,000 MWe of electricity generation and nearly 570 MWt of thermal energy in direct use applications, the potential for growth is substantial.

However, the cost of geothermal heat and electricity remains higher than the least-cost conventional technologies. Significant work is needed to lower costs and create incentives to spur the market for geothermal heat and power.

The DOE geothermal program is conducting more than 40 projects in fiscal year 2002. The goal of these projects is to improve technology (and thereby lower costs) for finding, characterizing, accessing, and producing geothermal resources, with strong involvement by industry partners.

This issue of *Geothermal Technologies* describes each R&D project within the Geothermal Technologies Program, and lists the national laboratory conducting the R&D.

The three major research areas are:

- Geoscience and Supporting Technologies.
- Exploration and Drilling, and
- Energy Systems Research and Testing.

Six national laboratories are performing the R&D. The labs, and the primary contact for their respective geothermal programs, are listed below.

Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho
Lead Lab—Geoscience and Supporting Technologies
Joel Renner, rennerjl@inel.gov, 208.526.9824

Sandia National Laboratories, Albuquerque, New Mexico
Lead Lab—Exploration and Drilling
Ed Hoover, erhoove@sandia.gov, 508.844.7315

National Renewable Energy Laboratory, Golden, Colorado
Lead Lab—Energy Systems Research and Testing
Gerry Nix, Gerald_nix@nrel.gov, 303.384.7566

(continued on page 2)

Lawrence Berkeley National Laboratory,
Berkeley, California
Mack Kennedy, bmkennedy@lbl.gov, 510.486.6451

Lawrence Livermore National Laboratory,
Livermore, California
Paul Kasameyer, kassameyer1@llnl.gov, 925.422.6487

Brookhaven National Laboratory,
Upton, New York
Marita Berndt, allan@bnl.gov, 631.344.3060

GEOSCIENCE AND SUPPORTING TECHNOLOGIES

Project Title: *Geophysical Measurements for Fracture Detection*
Organization: Lawrence Livermore National Laboratory

LLNL is developing methods to measure the fracture or crack density within a geothermal field, and the direction to fractures several meters from a borehole. We will complete the testing of the GEO-BILT electromagnetic logging tool that will produce valuable three-dimensional information about lithology and the nature of reservoir fluids, and orientation of permeable zones within several meters of a wellbore, can be inferred. We will continue to conduct laboratory studies of intact and fractured geothermal rocks at reservoir conditions to demonstrate how electrical anomalies can be used to locate zones of high fluid permeability. The time-dependence of resistivity change will be modeled with a multi-phase code such as NUFT or Tetrad.

Project Title: *Reinjection of Chemically Modified Geothermal Brines*
Organization: Lawrence Livermore National Laboratory

We are starting a new modeling and field study to evaluate the effect of injection of chemically modified fluids on the geothermal reservoir and on injectivity over time. Examples of significant issues related to reinjection are as follows: Although rock is an efficient buffer, what components are added to the fluid when the most soluble minerals dissolve? Is the solution composition changed? Are toxic elements leached from the rock that will cause problems if produced later? If the rocks are iron-rich, could iron be released and re-precipitate to drastically clog permeability? How does the reduction in porosity/permeability from silica precipitation balance the potential increases from mineral dissolution, if they occur in the same locale at all? Is reduced reinjectivity due mainly to wellbore precipitation, or reactions in the formation? Recent work also suggests that injection of chemically modified brines can affect the strength of rocks, and induce subcritical cracking over time.

Project Title: *Improved Geothermal Reservoir Management*
Organization: Idaho National Engineering and Environmental Laboratory

The large capital investment for geothermal development requires careful management of both reservoir production and power plant operation to sustain resource production and optimize electrical generation. Reservoir management, power plant operations, and time-related sales price can be jointly optimized to obtain various short- and long-term economic goals and resource sustainability. The purpose of this project is to investigate relationships between reservoir production, power plant operation, and pricing to determine scenarios for geothermal production. The project will consist of field studies with tracer tests and analysis of the tests. The study will also compare baseline operations of an existing Basin and Range binary plant against optimized operations to demonstrate improved resource management.

Project Title: *Solubility and Phase Equilibria of Fluorocarbon Tracers*
Organization: Idaho National Engineering and Environmental Laboratory

This study will evaluate candidates for applicability as geothermal tracers by providing physical property data of candidate fluorocarbon tracer compounds in water and geothermal brine. This data will be used in: a) determining the candidate compound's utility as a geothermal tracer and b) measuring properties necessary for predicting transport properties.

Project Title: *Tracer Test Interpretation Methods for Reservoir Properties*
Organization: Idaho National Engineering and Environmental Laboratory

The purpose of this project is to develop tools that can be used to interpret tracer tests and obtain estimates of reservoir and operational parameters. These tools (mostly in the form of spreadsheet applications) will be developed from an examination of energy and mass conservation equations, and can be used to optimize geothermal resource management.

Project Title: *Structural Geology and Geophysics at Dixie Valley, Nevada*
Organization: Idaho National Engineering and Environmental Laboratory

This research is undertaken to develop a greater understanding of the subsurface geometry of faulting in the region surrounding the geothermal reservoir at Dixie Valley, Nevada, by merging the field observations with available geophysical data and borehole information. The study will generate a detailed structural geologic map of the region surrounding the reservoir and provide geological interpretations and conceptual modeling of the area. The resulting conceptual model will be used as a basis for further exploration in Dixie Valley and in the Basin and Range province in general.

Project Title: *Studies of Geothermal Reservoir Dynamics*
Organization: Lawrence Berkeley National Laboratory

Reservoir simulators include only rudimentary capabilities for chemical transport and rock-fluid interactions. To optimize field development and management, industry needs more accurate and comprehensive simulation capabilities that can incorporate geochemical and geophysical information. LBNL's simulation codes TOUGH2, iTOUGH2 and TOUGHREACT will be applied and enhanced to model the behavior of noble gases and other phase-partitioning tracers, and rock-fluid interactions during production and injection operations. Post-processing routines for predicting geophysical signatures of reservoir conditions and processes will be developed. Geochemical, isotopic, flow, and enthalpy data from The Geysers will be analyzed to better understand the properties of the high-temperature reservoir fluids and the effect of limited injection.

Project Title: *Geophysical Methods for Resource Exploration and Monitoring*
Organization: Lawrence Berkeley National Laboratory

The extreme heterogeneity, anisotropy, and mixed fluid phases found in many geothermal areas pose significant challenges for "conventional" seismic imaging technology. Needed is an extension and adaptation of current methodology to optimize state-of-the-art multi-component 3-D and 4D seismic imaging methods for geothermal application. There will be three principle activities: (1) 3D modeling of elastic wave propagation in fractured/heterogeneous reservoirs, (2) integration of seismic methods, and (3) data processing and interpretation.

Project Title: *High-Temperature Instrumentation and Tools*
Organization: Sandia National Laboratories

Logging (downhole measurements from within a geothermal wellbore) is generally required during drilling, during reservoir evaluation, and during production. Task 1 –Having made the discovery that eliminating phosphorus from the optical fiber greatly reduces degradation in geothermal wells, a long-term test in a production well at Dixie Valley will be set up. Task 2–Consult and advise on building and testing an improved liquid-sampler tool. Task 3–Compare logging tools for accuracy and/or weaknesses. Task 4–Evaluate the feasibility of upgrading a televiewer to operate at higher temperatures.

Project Title: *University Research Grants*
Project Manager: J. Nathwani, (208) 526-0239
Organization: DOE Idaho Operations Office

In order to broaden the scope of reservoir engineering and geoscience research in the geothermal program and to entertain new and novel research approaches, DOE-ID requested proposals for research over several years. INEEL monitors technical performance and collects, integrates, and disseminates information from the research grants. DOE-ID issued a new solicitation to include high-risk EGS-related research projects.

Project Title: *Enhanced Geothermal Systems (EGS)*
Organization: DOE Idaho Operations Office

Ultimately, this will lead to an increase of the electrical power from geothermal resources. New, viable, and geographically diverse geothermal resources are a most critical aspect for bringing more geothermal kilowatts on line. DOE-ID selected the Phase II participants to continue development of field projects to verify EGS technology. One of the Phase II projects will be selected for continuation funding that will lead to Phase III, field validation of EGS technology. DOE-ID will issue a second EGS solicitation to test an EGS system not associated with existing production.

EXPLORATION AND DRILLING

Project Title: *Reconnaissance for Hidden Resources*
Organization: Lawrence Livermore National Laboratory

The goal is to evaluate techniques that allow the exploration of large areas, to identify specific locales that might contain new geothermal resources. The 20-year-old USGS survey of geothermal resources in the United States estimated that the undiscovered resource was substantially larger than the known resource. Most of the known-resource areas have since been explored or tested, but very little

exploration is targeted toward the undiscovered resource. Two methods have potential for covering large areas and detecting anomalies associated with those systems. The DOE-funded Hyperspectral Imaging Project has demonstrated airborne geobotanical remote sensing at Long Valley. A combination of satellite-based techniques can detect localized strain around hydrothermal systems, and regional strain that may show where faults are favorably oriented to maintain vertical permeability.

Project Title: *Basin and Range Exploration*
Organization: Idaho National Engineering and Environmental Laboratory

The Basin and Range is thought to be the largest geothermal exploration province in the United States, but unanswered questions limit the ability of operators to successfully explore for geothermal resources at low cost and with a high success ratio. A better understanding of the geologic setting and the native state geophysical signature of geothermal systems in the Basin and Range is essential for successful exploration. Completing the analogue study of the Dixie Valley geothermal system will enhance operators' understanding of Basin and Range systems. This task will consist of: correlation of new subsurface data with surface mapping and regional geophysical data, and expansion of the area mapped during 2000 and 2001 to include the northern termination of the Stillwater Fault, and assisting with the planning and interpretation for the separately funded, high-resolution aeromagnetic survey to be done by the USGS. Simulation studies are also planned to examine the native state geophysical signature of typical Basin and Range geothermal reservoirs. These studies will combine native state reservoir modeling with geophysical modeling. Where appropriate, these numerical studies will be validated through field testing, using geophysical data on existing geothermal fields.

Project Title: *Innovative Geothermal Exploration Techniques*
Organization: Lawrence Berkeley National Laboratory

To assist the geothermal industry in finding and operating geothermal fields we must develop (1) a more thorough understanding of known geothermal resources and (2) new innovative techniques for finding "hidden" geothermal systems. The project will take an integrated approach by calling on geophysical, geochemical, geologic, and remote sensing techniques as potential tools for expanding exploration capabilities for U.S. geothermal industries. Tasks include: Rapid resource evaluation via airborne electromagnetic (EM) and gravity principal component analysis; imaging geothermal reservoir signatures using high resolution satellite observations; simulation of coupled subsurface and subaerial CO_2 gas emissions for design of instrumentation and survey strategies for locating hidden geothermal systems; isotope geochemistry applied to locating and characterizing "non-conventional" surface manifestations of hidden geothermal systems; field case studies to evaluate earlier exploration efforts and to identify new approaches to assess U.S. geothermal resources; and evaluation of new 3-D magnetotelluric data acquisition systems and imaging algorithms for geothermal resource exploration.

Project Title: *3-D Magnetotelluric Modeling*
Organization: Sandia National Laboratories

Electrical and electromagnetic methods are currently used in geothermal exploration to detect subsurface resistivity patterns that indicate geothermal resources. Of the EM methods, the magnetotelluric (MT) method is the most effective and commonly used tool. By mapping the geometry of the 200 to 2000m thick, conductive argillic alteration that normally lies over and adjacent to high temperature geothermal systems, MT is used to target wells and assess reservoir generation capacity. Despite recent significant progress in EM data collection and processing, significant issues regarding MT data interpretation still act as barriers to routine use by the geothermal industry. Development of standard data sets to act as test beds for imaging schemes will provide the needed standards for testing MT interpretation.

Project Title: *Geothermal Resource Exploration and Definition Solicitation*
Organization: Sandia National Laboratories

This project is in support of the cost-shared exploration projects that will lead to the definition of new geothermal resources. This project has the primary objective of developing collaborative, interactive (Industry/DOE) efforts to support the exploration leading to the definition of these new geothermal resources. The work scope consists of funding and managing seven cost-shared cooperative agreements with industry participants and the development of a new solicitation for additional projects.

Project Title: *High-Temperature Instrumentation*
Organization: Sandia National Laboratories

Measurement-while-drilling, well logging, and reservoir characterization require electronic packages that can survive the hot, corrosive environment of geothermal wells. High-temperature electronics will provide optimized drilling controls and improve reservoir definition, thus reducing geothermal drilling costs by reducing the number of wells needed to produce a geothermal reservoir. There is, therefore, significant incentive for improving the temperature rating of instruments for downhole use in geothermal wells. The program in high-temperature instrumentation focuses on developing sensor systems and controllers using unshielded electronics (not requiring a Dewar) that can be exposed to high temperatures for indefinite periods. The major thrust of this effort is silicon-on-insulator (SOI) technology, which has been demonstrated both in the laboratory and in the field.

Project Title: *Wellbore Integrity and Lost Circulation*
Organization: Sandia National Laboratories

Lost circulation (LC) occurs when formation-fluid pressure is less than the fluid column pressure in the wellbore, so that some of the drilling fluid escapes into the formation instead of recirculating back up the well annulus. Lost circulation is often accompanied by further loss of wellbore integrity including sloughing, caving, washing out, or bridging. These phenomena are persistent in

geothermal drilling, are very expensive—often accounting for 10-20% of the total cost for drilling a typical geothermal well—and cause many additional drilling problems such as stuck drill pipe, damaged bits, slow drilling rates, and collapsed boreholes.

These problems are being addressed in four general ways: optimum application of current technology; development of new tools to quickly detect and characterize lost circulation zones before they cause additional problems; development and demonstrate of advanced treatment materials; and search for revolutionary ways to provide wellbore integrity. Work is being done to "down select" and optimize to the best currently available polyurethane formulation including evaluating one-part vs. two-part formulations.

Project Title: *Hard-Rock Drill Bit Technology*
Organization: Sandia National Laboratories

Background: Hot, hard, abrasive, and fractured rock formations are routinely encountered when drilling geothermal wells. Consequently, rock penetration rates are generally very low, and bit life is extremely limited. Both of these problems contribute significantly to the cost of geothermal wells. If penetration rates and bit life could both be doubled from their current typical levels, well costs could be reduced by about 15%.

The hard-rock drill bit technology project is a national-laboratory/industry/university cooperative research and development effort aimed at producing drag cutters and bits capable of more economical drilling in geothermal formations. Our mission is to coordinate this overall effort and to maintain and apply state-of-the art expertise and capabilities for technical consulting, analysis, and laboratory testing.

Project Title: *Cost Database and Simulators*
Organization: Sandia National Laboratories

A detailed understanding of drilling costs and their sources is necessary to focus efforts on work that has the highest payoff for the geothermal industry. For this purpose, SNL developed a spreadsheet-based cost model for estimating geothermal drilling costs and their origins. A method for evaluating the impact of research is also needed. Actual well-cost data are necessary to validate the model and measure the success of the program. The validated model will then become useful for investigating where technology development will lead to cost reductions.

Project Title: *Diagnostics-while-Drilling (DWD)*
Organization: Sandia National Laboratories

Drilling is an essential and expensive element in the exploitation of geothermal energy for power production. The central concept of DWD is a closed feedback loop, carrying data up and control signals down, between the driller and tools at the bottom of the hole. Up-coming data will give a real-time report on drilling conditions, bit and tool performance, and imminent problems. Cost analyses indicate that DWD technology would reduce the bus-bar cost of geothermally generated electricity by up to 30%, depending on well depth, well productivity, and the type of geothermal reservoir.

Project Title: *Acid-Resistant Cements*
Organization: Brookhaven National Laboratory

Calcium aluminate phosphate (CaP) cement was developed at BNL in collaboration with Unocal and Halliburton Energy Services as CO_2-resistant cement for wells exposed to temperatures up to 280°C and was successfully used to complete geothermal wells in Indonesia. The cement was commercialized under the trade name "ThemaLock Cement" by Halliburton Energy Services in 1998. Consequently, this technology received a "2000 R&D 100 Award". In 2001, emphasis focused on improving two properties of this CaP cement: its acid resistance in surface groundwater at ~ 90°C, and its toughness-associated mechanical behaviors. BNL will evaluate the effectiveness of two anti-acid admixtures in conferring greater acid resistance, water-dispersible silicon emulsions and alkaline metal hexafluoro compounds.

Project Title: *Cement Structural Response Analysis*
Organization: Brookhaven National Laboratory

FY2001 investigations led to the conclusion that traditional guidelines for well cements are deficient, especially when it comes to the cement mechanical property requirements. Current studies from the oil and gas industry are reaching similar conclusions. Failure modes will be investigated for their relevance to cement mechanical properties. Improved material definitions will be obtained through the characterization of conventional, lightweight, and fiber-reinforced cements.

ENERGY SYSTEMS RESEARCH AND TESTING

Co-production of Silica and Other Commodities from Geothermal Fluids

Silica Scale Inhibition

Mitigation of Impact of Off-Design Operation

Power Plant Costing Methodology

Enhancement of Air-Cooled Condensers

Microbiological Research

Continual Removal of Non-Condensable Gases For Binary Power Plant Condensers

Pipe Coatings

Geothermal Process Gas Monitors

Heat Exchanger Field Tests

Field Demonstration and Evaluation of Lined Heat Exchanger Tubes

High-Performance Coating Materials

Air-Cooled Condensers

Project Title: *Co-production of Silica and Other Commodities from Geothermal Fluids*
Organization: Lawrence Livermore National Laboratory

The objective is to develop silica and lithium extraction techniques that produce marketable by-products at specific field sites. Produced geothermal brines contain large quantities of dissolved silica that often forms scale in power production facilities. Work to date has focused on laboratory silica precipitation experiments using simulated Salton Sea geothermal brines. The goal is to develop a working silica precipitation process that produces silica with properties that match a targeted silica market.

Project Title: *Silica Scale Inhibition*
Organization: Lawrence Livermore National Laboratory

The objective is to inhibit silica scale formation in geothermal power plants. Despite the costs associated with preventing scale formation and/or removing and disposing of scale, the geothermal industry lacks effective, economical, and generally available silica scale inhibitors. To complicate matters, variations in fluid chemistry and plant conditions among geothermal fields can cause the effectiveness of an inhibitor to vary widely. Anti-scalants best suited for inhibiting silica scale formation will be identified by evaluating their ability to intervene in the key steps leading to scale deposition.

Project Title: *Mitigation of Impact of Off-Design Operation*
Organization: Idaho National Engineering and Environmental Laboratory

Because geothermal resources (especially liquid-dominated) are relatively low-temperature energy sources, changes in the resource or ambient temperature can have a significant impact on plant performance. The task objective is to identify and evaluate methods of minimizing the effects that operating at off-design conditions have on the power generation from geothermal binary power plants, and to define operational schemes that will increase plant revenues and minimize operating costs.

Project Title: *Power Plant Costing Methodology*
Organization: Idaho National Engineering and Environmental Laboratory

The viability and future growth of the domestic geothermal industry is contingent upon reducing both operating and capital costs. In order to assess whether advances in technologies for energy conversion systems are reducing these costs, it is necessary that costs for components and activities related to the production of electrical power are adequately defined. In this project, methods are being developed that will allow power plant costs to be determined in detail sufficient to assess the large cost items and the impact of technology improvements on the cost of these plant components/systems.

Project Title: *Enhancement of Air-Cooled Condensers*
Organization: Idaho National Engineering and Environmental Laboratory

Binary geothermal plants lacking a supply of water for an evaporative cooling system reject heat directly to the ambient. Because air is a poor heat transfer medium, a large surface area of the condenser tubes is required. An EPRI report indicates that the cost of air-cooled condenser can be up to ~25% of the total plant cost (including well field). Improving the performance of the condensers is expected to have a significant impact on reducing the cost of power generated from these plants. The objective of this project is to improve air-cooled condenser heat transfer performance (overall heat transfer coefficient) by at least ~15%, resulting in lowering condenser cost without increasing the air-side pressure drop and fan parasitic power consumption.

Project Title: *Microbiological Research*
Organization: Idaho National Engineering and Environmental Laboratory

The high densities of microorganisms found in geothermal plant cooling systems may impact their operational efficiency either directly by reducing heat transfer through condenser systems or cooling towers, or indirectly by altering the interfacial chemistry of metallic substrates influencing corrosion. In addition, microbiological activity may reduce the effectiveness of corrosion inhibitors, protective coatings, or other chemical treatments used in the plants. The economic impact of this activity has been estimated to be as high as $500,000 annually for a 100 MWe plant. In spite of the high costs associated with biofouling, few plants have biological monitoring programs in place. This work is aimed at investigating the impacts of microbiological activity on the efficient operation of geothermal power production facilities and supporting the industry in identifying and mitigating these effects.

Project Title: *Continual Removal of Non-Condensable Gases For Binary Power Plant Condensers*
Organization: Idaho National Engineering and Environmental Laboratory

The presence of non-condensable gases (NCGs) in a vapor condensing on a cold surface is known to degrade heat transfer coefficients and raise condenser pressure. Binary plants have NCGs in their working fluid vapors that can be introduced into the system several ways. This results in an average turbine output that is reduced from what would be obtainable with a minimum NCG content in the condenser. In order to increase turbine output, continual removal of NCGs would be beneficial. Because membranes have been developed for the separation of condensable organic vapors from NCGs, a membrane system for this continual removal has been proposed. Research will be conducted to validate the use of a

membrane-based technology as a cost-effective means for continual removal of non-condensable gases from binary power plant condensers. Successful development of this technology will minimize the performance penalty associated with these gases and will reduce the working fluid losses associated with current removal methods.

Project Title: *Pipe Coatings*
Organization: Idaho National Engineering and Environmental Laboratory

Extreme geothermal operating environments cause corrosion and force the use of exotic materials for piping and components, or require frequent replacement of these components if common materials of construction are used. This effort will reduce the maintenance cost due to corrosion. This project investigates the functionality of thermally sprayed coatings for geothermal applications as a substitute for costly bulk materials. Both the technical feasibility and the potential to reduce costs will be validated so that geothermal companies can directly acquire the services from coating companies.

Project Title: *Geothermal Process Gas Monitors*
Organization: Idaho National Engineering and Environmental Laboratory

Geothermal plants contain gaseous and particulate species in process streams that require abatement to minimize equipment damage, maximize performance, and/or meet regulatory requirements. These abatement processes involve the use of costly chemicals or the consumption of energy. The objective of this program is to lower the cost of geothermal power production through the development and verification of low maintenance instrumentation for the real-time detection and control of various process parameters.

Project Title: *Heat Exchanger Field Tests*
Organization: National Renewable Energy Laboratory

Heat exchangers in service at geothermal power plants are often exposed to highly fouling and corrosive brine. This task is developing low-cost polymer coatings to be applied to inexpensive carbon steel shell-and-tube heat exchangers in geothermal service. The coated steel will have corrosion resistance, maintainability, and durability equivalent to high-alloy stainless steels or nickel-based alloys. The results from field tests in previous fiscal years have demonstrated that polyphenylene sulphide (PPS)-based coatings are the most effective in geothermal service. This task will conduct field tests of PPS coatings with a variety of filler materials at various sites. Tests last a minimum of six months and monitoring and evaluation will continue into following fiscal years. This task includes working with industry to commercialize the technology. The formulations and application methods will be altered to address weaknesses evident in the test results.

Project Title: *Field Demonstration and Evaluation of Lined Heat Exchanger Tubes*
Organization: Brookhaven National Laboratory

BNL in collaboration with NREL has worked to optimize the formulation of material systems possessing excellent thermal conductivity and corrosion/oxidation/wear/fouling. A yearlong field validation test at Mammoth Pacific showed that the lining systems remained intact, demonstrating their outstanding performance in protecting the tubes against corrosion and fouling. Bob Curran & Son Corp. commercialized this lining material system in 2001, under the trade name "TS-2500". The factors to be assessed will include the liner's thickness, surface roughness, and its adherence to underlying tube surfaces.

Project Title: *High-Performance Coating Materials*
Organization: Brookhaven National Laboratory

In 2001, focus was on developing a technology that improves the mechanical behaviors and enhances the thermal conductivity of boehmite ceramic-and SiC grit-incorporated PPS materials. These materials are intended for use up to 200°C. Chopped carbon fibers incorporated into the PPS matrix significantly improved these properties. The carbon fiber-reinforced PPS composite coatings exhibited outstanding mechanical properties. The thermal conductivity of the non-reinforced PPS increased ~ 60 % after adding an appropriate amount of fiber. One important question still remained: How to repair any damage caused by micron- and nano-sized cracks generated in the matrix during mechanical loading and service life, and also, how to retard growth of the crack. An exposure test for the panels with these new coatings will be performed at the Mammoth Pacific and East Mesa Power Plants to evaluate their usefulness for heat exchanger tubes. The susceptibility of the new coating surfaces to silica scale deposits will be assessed.

Project Title: *Air-Cooled Condensers*
Organization: National Renewable Energy Laboratory

Because of the thermodynamics of operating power cycles at typical geothermal resource temperatures, approximately 90% of the heat extracted from the ground must be rejected to the environment. As a result, condensers account for as much as 30% of total plant capital cost or 20% of electricity cost. Water-cooled condensers are preferable from a performance standpoint, although air-cooled condensers are widely used in geothermal power plants because of the lack of clean cooling water. The cost of geothermal electricity can be decreased significantly if performance of the heat rejection systems can be improved. This is especially true for air-cooled plants during summer operation when electric output can drop by 40% due to elevated air temperatures.

NREL has developed spreadsheet and other computer-based models to evaluate the impact of improved condenser designs and operation strategies. NREL also developed a spreadsheet to compare the cost and performance of various options for evaporatively pre-cooling air. NREL is also investigating ways to combine water cooling with air cooling and the potential advantages of using evaporative condensers instead of shell-and-tube condensers at the new Empire 1 MW power plant.

Project Title: *Component Development for Ammonia/Water Power Cycles*
Organization: National Renewable Energy Laboratory

NREL researchers designed a prototype absorber/cooler (air-cooled) with specific considerations for mixing of vapor with lean liquid inside this component as well as enhanced air-side heat transfer coefficient. Benefits of this work are many, including reduced condenser size (and hence reduced cost), and reduced turbine back-pressure (and hence increased power generation). NREL has developed a procedure for the design and fabrication of this type of finned plate heat exchanger that can operate at high pressures. However, this procedure needs to be significantly modified to be cost effective. The significance of this task is that it will provide a much needed heat rejection system that utilizes air instead of water and will not have problems associated with tube and shell configurations.

Project Title: *Plant Performance Enhancement and Optimization*
Organization: National Renewable Energy Laboratory

This task characterizes the performance of geothermal power plants and investigates methods to enhance their overall performance from a system point of view. One opportunity is to improve the chemistry for the hydrogen sulfide abatement. NREL and others will investigate potential means for reducing the consumption of chemicals in the abatement process.

Project Title: *Geothermal Silica Recovery*
Organization: Brookhaven National Laboratory

Silica precipitation as a scale in geothermal power plants is an operating problem. This task will develop brine treatments to reduce silica scale formation, and collaborate and support the pilot tests for amorphous silica production.

Project Title: *High-Temperature Polymeric Elastomers*
Organization: Brookhaven National Laboratory

A serious problem confronting geothermal power plant is the failure of the down-hole pumps. The harsh, hostile environment quickly causes significant damage to the pumping equipment, particularly to the pump's shafting component. Thus, the existing down-hole pumps must be modified to deal with this problem. High-temperature performance polymeric elastomers are very attractive materials to use in the new bearing system of conventional pumps because they may mitigate damage to the shafting components, and allow the oil lubricant to be replaced by a water one.

Project Title: *Non-Destructive Testing*
Organization: Brookhaven National Laboratory

The non-destructive testing (NDT) program for evaluating corrosion and erosion-corrosion of geothermal piping systems focused on experimental and modeling studies with the objective of applying more reliable and cost-effective methods for condition assessment. The primary type of NDT to be investigated in FY02 will be based on long-range guided wave propagation. Research will also be performed on integration of the results from NDT with remaining strength and life assessment and reliability centered maintenance. Different methodologies for predicting remaining strength and life will be investigated.

Project Title: *Field-Verification of Small-Scale Geothermal Power Plants*
Organization: National Renewable Energy Laboratory

Small-scale geothermal power plants are attractive because they offer a geothermal means to provide distributed power and expand geothermal use to states that have not been large users of geothermal energy. Solicitations were issued and five projects were awarded. Each project consists of three or four phases: I) preliminary design, IA) well drilling (if necessary), II) detailed design, and III) construction, and operation and data collection for a 3-year period.

Project Title: *Direct Use Field Verification*
Organization: National Renewable Energy Laboratory

A competitive solicitation was issued to establish collaborative, cost-shared, direct use geothermal projects. Five subcontracts were placed. In addition, subcontracts are being placed with the Oregon Institute of Technology and Washington State University to integrate these pools of expertise into a DOE center of excellence for direct use. The following activities will be performed: provide technical support and direction of 3-5 subcontracted direct use projects to be operated and evaluated for at least three years to show proof-of-concept of the project concepts and identify research and technology developments needs to reduce cost, reduce O&M, increase reliability and improve cost effectiveness; initiate a technology transfer/market development activity targeted at potential users and project developer; identify near-term technology development and engineering improvement requirements that the Program or the geothermal equipment industry should perform; develop, maintain and make analytical tools and models available to users; perform technology transfer/information dissemination; and plan and conduct a "Geothermal Direct Use Pre-feasibility Studies" competitive solicitation.

How to Reach Us

U.S. Department of Energy
Office of Geothermal Technologies
1000 Independence Ave., S.W.
Room 5H-048
Washington, DC 20585
(202) 586-5340
www.eren.doe.gov/geothermal