

Phase II. The location and brief description of the projects are as follows:

**Rye Patch, Nevada.** Mt. Wheeler Power, Inc., is developing a high-temperature site at Rye Patch, Nevada. A well will be drilled through a shallow limestone target and then drilled directionally to attempt to intercept the Rye Patch fault at greater depth. The Rye Patch site has a partially completed power plant that could enable rapid development of this resource if the drilling program is successful. An exploration report has been completed (no additional geophysics were required), a well site has been selected, and Phase II negotiations are nearing completion.

**Blue Mountain, Nevada.** The Noramex Corporation has completed Phase I reporting with no additional geophysics required, and negotiations for Phase II have begun. A 600-meter well will be drilled to confirm the existence of a high-temperature geothermal reservoir associated with overlapping spontaneous potential, resistivity, and shallow temperature gradient anomalies, and to determine the reservoir's production characteristics.

**Cove Fort-Sulphurdale, Utah.** The Utah Municipal Power Agency is in Phase I exploration to locate and drill a 900-meter well to explore the western extension of the Cove Fort-Sulphurdale geothermal area. Geophysical exploration consists of resistivity, ground magnetic, and microgravity surveys. The Agency has a power plant at Cove Fort with additional capacity available, so the western extension of the reservoir could be used immediately.

**Steamboat, Nevada.** SB Geo, Inc., is investigating a shallow boiling reservoir in the northern Steamboat Hills and Steamboat Springs area of Nevada. Phase I is complete (no additional geophysics work was required), and a 760-meter well will be drilled to verify an extension of the Steamboat Springs resource, if sufficient funding is available. Given the existing power plants and grid structure in the area, additional geothermal power could be brought online quickly if this project is successful.

**Under Steamboat, Nevada.** Another project in the Steamboat area (named U-Boat, for Under Steamboat) is being conducted by the Coso Operating Unit of Yankee Caithness Joint Venture, LLC. Phase I geophysical exploration of the deep geothermal resource beneath the Steamboat Hills region is underway, using seismic and gravity studies. These results, combined with data from micro-earthquake studies, will be used to locate the deep fault system and productive zone at U-Boat.

**Lightning Dock, New Mexico.** Ormat International, Inc., is investigating a deep, high-temperature resource in the Lightning Dock Known Geothermal Resource Area. Extensive Phase I work includes seismic, gravity, and resistivity surveys to determine the strike of the Animas Valley Fault in southwestern New Mexico. The geophysical data, combined with existing information, will enable siting an exploratory well. The well will then be tested to assess the geothermal capacity of the resource.

In summary, three of the projects have completed Phase I work, and negotiations are underway to develop Phase II projects, subject to the availability of DOE funds. The objective is to bring these projects through all three phases, and therefore define new geothermal capacity in Nevada, Utah, and New Mexico. Depending on future funding levels, a second GRED solicitation may be issued to define additional geothermal resources.

For more information, please contact Norm Warpinski at Sandia National Laboratories, 505.844.3640, [nrwarpi@sandia.gov](mailto:nrwarpi@sandia.gov).

## ormations

*Sandia National Laboratories, with funding from DOE, has worked with DynaFlow, Inc., and Security DBS to develop a polycrystalline diamond compact (PDC) drill bit with five passive jet nozzles (no moving parts) that emit self-resonating, pulsating mud streams. These cavitating jets both "pre-weaken" the rock surface and clear rock debris for more efficient cutting. The addition of mudjets makes PDC bits very attractive for use in the high-temperature, hard, abrasive formations encountered in geothermal drilling.*

Roller cone bits have been most widely used in geothermal drilling, but the seal and bearing assemblies that allow rotation of the cones are prone to fail at the high temperatures characteristic of geothermal formations. Furthermore, roller cone bits often suffer from slow penetration rates in these hard formations. The maturity of this bit technology offers little promise for major technological improvements. On the other hand, PDC bits are used extensively in oil and gas drilling. The lack of moving parts, high-temperature resistance, and aggressive cutting structure of PDC bits make them an attractive alternative for geothermal drilling. However, hard geothermal formations induce large forces on the cutters of the PDC bit, which can lead to high wear rates on the cutters. Hard rock also presents problems with impact-type failures in the PDC cutters if significant bit vibration occurs within these formations. Both of these concerns are addressed with the Sandia mudjet PDC bit by reducing the forces on the PDC cutters at the rock interface.

To reduce the magnitude of the forces, high-pressure jets augment the rock removal process. Mudjets allow PDC cutters to penetrate rock more efficiently by two mechanisms. First, the jets keep the rock/cutter interface clean of rock cuttings, thereby increasing the penetrating stresses in the rock. Second, the high-pressure fluid can enter and hydraulically extend fractures created by the cutter, thereby pre-weakening the rock.

The mudjet nozzles pulsate passively due to a resonance set up in a tuned chamber upstream of the nozzle orifice. DynaFlow's tuned organ pipe nozzle design produces vortex-shedding jets that cavitate more effectively and at greater wellbore depths than jets produced by conventional nozzles. These pulsating jets are also more effective than conventional jets in eroding a rock surface because the collapsing cavities spawn microjets that produce very high impact pressures. The jet pulsations assist with lifting the rock cuttings off the bottom where they are held down under large hydrostatic well pressures.

The bit is intended to use readily available rig pressures, i.e., up to 5000 psi. Sandia analyzed an 8-1/2" diameter Security DBS bit and selected those cutters for augmentation that would provide the greatest improvement in bit performance. DynaFlow conducted laboratory testing to specify the organ pipe and orifice configurations. Security DBS integrated the organ pipe and orifice configurations into their matrix-body PDC bit, and manufactured the bit following a project-team design review. A computer model produced by Security DBS showing the flow geometry for the tuned organ pipes housed within the bit is shown in Figure 1. A face view of the actual bit with the nozzles directed at the bit blades is shown in Figure 2. The bit design features removable nozzle assemblies such that it can be used with either cavitating or conventional nozzles to allow the relative benefits of high-pressure jets to be evaluated with a single bit.

DynaFlow encountered erosion in the orifices during laboratory testing using conventional orifice materials (tungsten carbide, stainless steel, and sapphire), all of which experienced significant erosion leading to a reduction in nozzle performance. Sandia then began work to identify an orifice material with improved abrasion resistance. Tungsten carbide-supported polycrystalline diamond was chosen for its erosion resistance. Sandia employed specialized fabrication

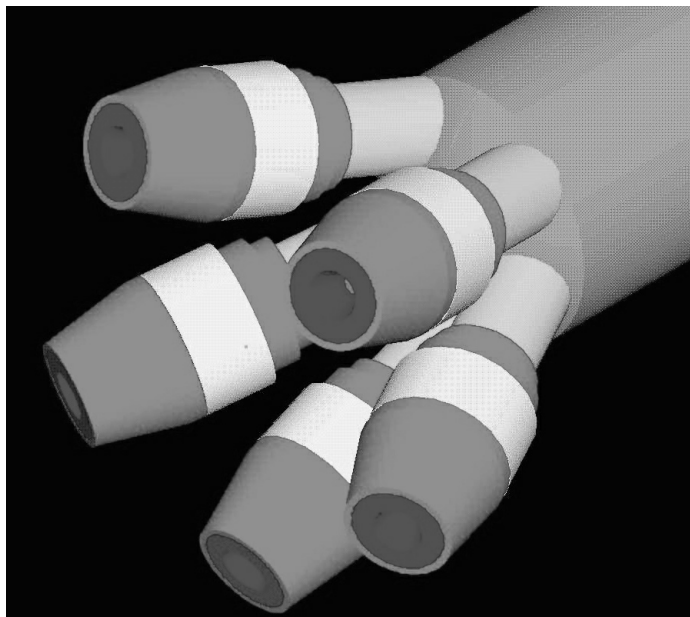


Figure 1. Computer model of organ pipe geometry and flow sections within the bit.

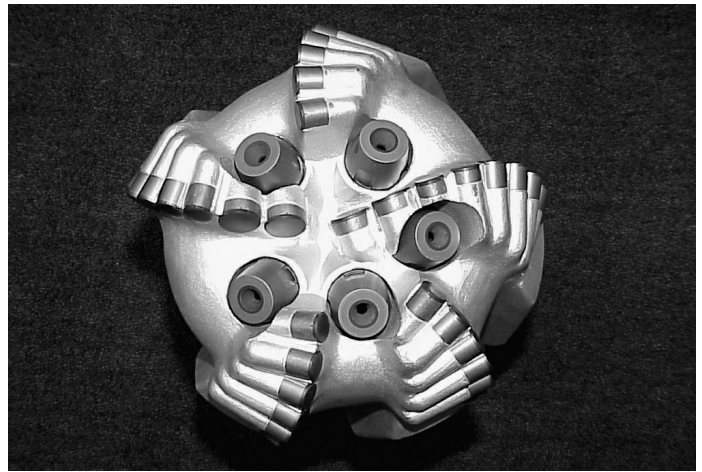


Figure 2. Face view of the mudjet-augmented PDC bit showing the cavitating jet nozzles/orifices augmenting each blade of the bit.

techniques to create the required profile in the throat of the orifice. The orifices are brazed into individual nozzle assemblies that are subsequently threaded into the bit body.

The nozzles/orifices were flow-tested to confirm erosion resistance to cavitation. Post-test inspection showed negligible erosion in the throat of the orifice, although marginal pitting was seen at the entrance to the orifice. (This erosion could be addressed by redesigning the orifice entrance.) During part of the flow-testing, the nozzles were allowed to impinge upon a sample of Nugget sandstone for 30 seconds, resulting in significant rock erosion. The bit was thereby qualified for subsequent drilling tests.

The mudjet-augmented PDC bit was then tested at the Drilling Research Laboratory at TerraTek, Inc., in Salt Lake City. The bit was tested with both standard nozzles and the cavitating jet nozzles in Crab Orchard sandstone, a rock representing the upper compressive strength for PDC bits currently used in production drilling. A conventional roller cone bit was also tested for comparison. As shown in Figure 3, the PDC bit drilled more than twice as fast as the roller cone. Furthermore, the rate of penetration of the

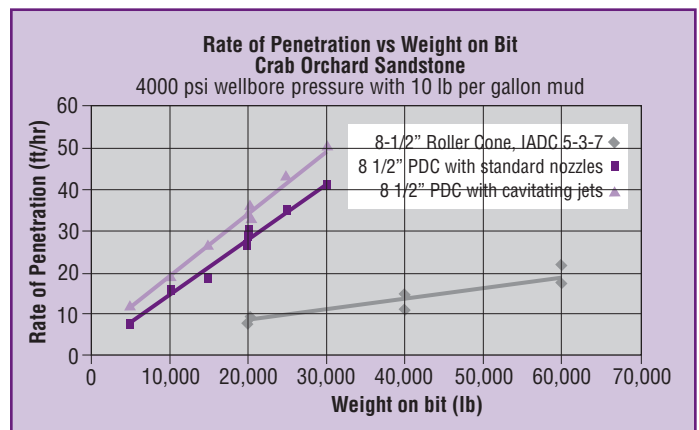


Figure 3. Results of the demonstration testing of the mudjet-augmented PDC bit. The unaugmented PDC bit drills at twice the penetration rate of a current-technology roller cone. Cavitating jets to augment the cutting action further improve penetration rate and reduce the weight on bit requirements for a PDC bit.

PDC bit with jet-augmentation increased up to 30 percent over that achieved with standard nozzles. At a given penetration rate, the jet augmentation reduced the requisite weight on bit, and hence the component cutter forces, by 20 percent or more. The PDC bit was also used with both cavitating and conventional nozzles to drill Sierra White granite, a rock occurring in geothermal formations, at rates in excess of 30 feet per hour.

Jet augmentation is just one of the directions Sandia is pursuing to extend the use of PDC bits to geothermal well development.

For more information, contact David Raymond, Sandia National Laboratories, 505.844.8026, email: [duraymo@sandia.gov](mailto:duraymo@sandia.gov); or Mike Prairie, Sandia National Laboratories, 505.844.7823, email: [mrprair@sandia.gov](mailto:mrprair@sandia.gov). Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for DOE.

## orkshop

Allan Jelacic, geothermal team leader in DOE's Office of Wind and Geothermal Technologies, presented DOE's Geothermal Energy Program goals in the opening session of the Stanford workshop on January 29, 2001:

- Double the number of states with geothermal electric power facilities to eight by 2006.
- Reduce the levelized cost of generating geothermal power to 3-5 cents/kWh by 2007.
- Supply the electrical power or heat energy needs of 5 million homes and businesses in the United States by 2010.

He stressed the three "E's" of the program in attaining these goals:

- Energy—use indigenous geothermal power to balance the national energy portfolio.
- Economics—use geothermal energy to capture domestic and international markets.
- Environment—limit the impacts of geothermal power production.

In the 1990s, there were no new domestic installations and virtually no growth in U.S. geothermal power production. Jelacic presented several reasons:

- Competition with fossil fuels—particularly natural gas until recent price increases
- Financing—concerns about small capitalization and perceived risk

- Long project lead times—the Glass Mountain example
- Siting and permitting—two- to five-year approval periods
- Obvious sites already taken—exploration is needed
- Industry focus overseas—because of weak U.S. activity

To overcome the lack of growth in domestic geothermal power production, partnership is essential. DOE's program structure contains national laboratories, universities, and most important—industry partnerships. Geoscience and supporting technologies, drilling, and energy systems research are the three components of this program structure.

Current projects involving DOE-industry partnerships include resource exploration, enhanced geothermal systems, and small-scale field verification. For FY 2000, seven DOE project awards for resource exploration and definition totaled \$827,000; nine awards for enhanced geothermal systems totaled \$1,736,000; and five awards for field verification totaled \$750,000.

Jelacic concluded that while the outlook for geothermal energy was cautiously optimistic, some challenges remain, such as the cost of electricity, defining new resources for development, access to public lands, stakeholder involvement, and electric utility restructuring.

Brookhaven National Laboratory (BNL) conducts research on durable, cost-effective materials for use in geothermal energy applications. Specialized materials are required to handle aggressive geothermal environments encountered during drilling, well completion, power production, and reinjection. BNL's interests include developing materials to better withstand high-temperature corrosive brines; optimal use of existing materials and technologies through improved basis for selection; reduction of capital, operation, and maintenance costs; life extension of equipment; and non-destructive testing. BNL's research program integrates experimental characterization of material properties, numerical modeling to predict *in situ* behavior, and field-testing in collaboration with industry. Materials investigated include cements, polymers, elastomers, composites, and corrosion-resistant alloys.

Recent successful research projects include heat exchanger tube coatings (Geothermal Technologies Vol. 5, No. 4, 2000), thermally conductive grouts for geothermal heat pumps (Geothermal Technologies Vol. 4, No. 4, 1999), and calcium phosphate well cements (Geothermal Technologies Vol. 5, No. 3, 2000). Brief descriptions of other recent and current projects follow:

### MICROBIOLOGICAL ATTACK OF CONCRETE

BNL has been working on prevention of microbiologically influenced corrosion (MIC) of concrete in cooling towers used in geothermal power plants. MIC of concrete is