Extracting Geothermal Energy Can Be Hard

Experience at the Baca geothermal field shows that withdrawing energy from the ground can be tougher than discovering the field

The initially high expectations of the mid-1970's for the rapid development of geothermal energy have been lowered. One reason is continuing uncertainty about the extraction of geothermal energy. Drillers can have a good idea of which areas have concentrations of geothermal energy beneath the surface and still have trouble bringing up enough energy to make a power plant worthwhile. The extraction problem has been highlighted by the recent termination of a federal geothermal demonstration project at the Baca field of the Valles Caldera, New Mexico, the sixth largest geothermal province in the United States. The problem at Baca is not necessarily insoluble, but it is tending to accentuate industry's cautious approach to geothermal exploration.

The Baca geothermal field sits atop the remains of a volcanic eruption 300 times the size of Mount St. Helens that 1.1 million years ago spewed ash over much of the Southwest. One hundred thousand years after the last major volcanic activity, steam, hot water, and gas still seep up through 2000 meters of ash-turned-rock in the Valles Caldera, the 20-kilometer-wide depression left from the cataclysmic eruption. This hydrothermal activity and the results of exploratory drilling in the 1960's encouraged Union Geothermal, a division of Union Oil Company of California, to lease 100,000 acres in 1971 and begin exploratory drilling.

By 1976, initial drilling results at Baca looked good. Five of the 11 wells produced commercially acceptable amounts of hot water and steam. That accounted for about one-third of the energy required for a 50-megawatt power plant. In fact, well tests indicated that the geothermal reservoir penetrated by the wells contains more than 1 trillion liters of hot water. At the time, Union estimated that eight 50-megawatt power plants could withdraw hot water and steam from the reservoir for 30 years. The first plant would require only another ten successful wells to meet its requirement, Union estimated.

In 1977, the Department of Energy (DOE) solicited competitive proposals for industry participation in a geothermal demonstration project; Union thought that Baca was a sound candidate. DOE, relying on its own experts as well as consultants at Lawrence Berkeley Laboratory (LBL) and the U.S. Geological Survey (USGS), agreed that there was little risk that the Baca reservoir could not support the energy requirements of a single power plant. DOE awarded the project to Union and the Public Service Company of New Mexico under a 50:50 government-industry funding arrangement.

To this day, no one doubts that the hot water is down there—the problem is that Union was unable to drill into enough of it soon enough to be sure of supplying even the single plant. Drilling subsequent to the signing of the cooperative agreement produced only two successful wells out of 13 attempts.

Part of the problem was the difficulty of drilling at Baca, according to a team of experts* appointed by DOE to review the experience at Baca. The rock is hard and is riddled by faults and fractures formed by the forces that have been shaping the Valles Caldera for the past million years. As at some other geothermal sites, the hot water flowing through these fractures and the natural voids of the rock is under less pressure than the drilling fluid that cools and cleans the drill bit. If standard drilling techniques were used, this drilling mud would be pushed into the permeable formations and baked into a permanent seal.

The problems that ensued from the rock and the under-pressure conditions were formidable: drill pipe corroded, stuck, or twisted off in the hole; drill-hole sides collapsed; drill-hole casing wore out or collapsed; and drilling fluids disappeared into unmapped permeable rock formations. Union encountered serious problems during three-quarters of its 31 drilling attempts, according to the review team. These problems not only cost money and time but made it more difficult for Union to decipher what it was that they were drilling through, the report says.

Understanding the nooks and crannies of the Baca reservoir proved to be the fatal problem for the demonstration project. Most of this volcanic rock is impermeable. What empty space exists as pores and microfissures is often not connected to other voids, so fluids cannot flow. Geothermal fluids themselves can isolate what permeable zones there are by depositing a mineral seal in the voids. Not all permeable zones even contain fluids. The trick, then, is to predict where in a jumble of fractures, faults, and partially sealed zones of permeability there is hot water that is free to flow into a well. This is a far cry from developing most major oil fields. Once found, a large oil field can be blanketed with a grid of wells, most of which will produce oil.

After failing to find more of these permeable productive zones after initial successes, Union developed a predictive model to guide their drilling. According to the review team, it emphasized the permeability provided by the faults along the edge of a block of rock that had dropped downward to form Redondo Canyon, the site of most of the drilling. Still not much luck. On 1 May 1981, Union formally notified DOE that it could not supply the required steam within a reasonable amount of time.

Failing to find enough naturally permeable production zones in the volcanic rock at Baca, Union suggested and DOE agreed to two alternative approaches. One was the creation of new fractures by hydrofracturing, the pumping of large volumes of fluid under high pressure into a short section of a well. Fractures did form in the two test wells, but apparently they did not intersect the natural, water-filled cracks. The other approach was extremely deep drilling aimed at the nonvolcanic limestone and granite underlying the volcanic rock of the caldera. Two deep wells encountered plenty of heat—temperatures reached as high as 341°C—but they found no flowing fluids and no permeability. In January 1982, the three parties decided to terminate their agreement.

In its postmortem of the Baca project, the review team suggested several ways that the search might have been made more successful. Examining the geological well data, the team concluded that half of the steam or hot water sources that drillers did manage to penetrate are

*The reservoir definition review team consisted of: D. Nielson, University of Utah Research Institute; N. Goldstein, M. Wilt, C.-F. Tsang, and G. S. Bodvarsson, LBL; A. Truesdell, USGS; W. Laughlin, Los Alamos National Laboratory; W. Holman and M. Molloy, DOE; S. Garg and D. Riney, S-Cubed, Inc. The review team's final report, LBL-14132, June 1982, is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Price code: A04.

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more-or-less flat-lying, permeable layers of volcanic sandstone or ash. Union included neither these zones nor faults that cut across Redondo Canyon in their drilling model, the team contends.

The team's report also noted that geophysical surveys helped locate regions that might contain geothermal reservoirs, but more intensive surveys, which might have more clearly delineated the extent of the reservoir, were not conducted. That such surveys could have been valuable, the report says, is suggested by the coincidence of all of the deep, productive wells with a single, 10-square-kilometer geophysical anomaly. All this, team members emphasize, is seen in hindsight. At the time, the Baca reservoir seemed to be simple and predictable. All that was required, everyone believed, was further drilling.

Union takes issue with these conclusions. The crosscutting faults and permeable strata are there, a spokesman says, but Union geologists do not believe that the positions of such flow paths are predictable enough to guide drilling operations. Likewise, geophysical surveys can be helpful in locating favorable areas, but in the geologically complex Rendondo Canyon area, more geophysical studies would do little to define new drilling targets, the spokesman says.

Even if such technical aids had boosted the drilling success rate at Baca, some researchers doubt that it would have been the productive geothermal field that Union expected. Gudmundur Bodvarsson (a review team member) and his colleagues at LBL have used their own methods to estimate the amount of hot water in the Baca reservoir and the practicality of withdrawing it to produce power.† They agree that there is more than enough hot water there, but ". . . it is questionable that [that portion of] the Baca field can supply enough steam for a 50 MW power plant for 30 years." That conclusion is controversial.

The problem, according to the LBL group, is that the very act of rapidly extracting fluids would cool the rock around the well, reduce the pressure there, and thus decrease the well's output. In the vicinity of a well, the hot water flashes to steam, soaking up thermal energy and cooling the reservoir. The low hydrostatic pressure and low permeability of the reservoir, which restricts the flow of fluids from a distance, promote such boiling. The measure of the ease of flow within a reservoir is called transmissivity. Its value at Baca is ten times smaller than at successfully developed fields such as The Geysers in California, the LBL group notes. Both the Union model for estimating generating capacity and the subsequently developed LBL model take account of transmissivity; Union's allows the entire reservoir to drain freely into a well but restricts resupply from outside the reservoir, while LBL's restricts flow within a subdivided reservoir. But the LBL group believes that their more complicated model is more realistic. That is unlikely to be proven until a geothermal reservoir is modeled both ways and then actually put into power production. A third opinion, as expressed by Roland Horne of Stanford University, is that reservoir modeling in either manner is "extremely problematical in fractured systems," since the models would contain too little information about the reservoir to be useful until it was too late.


Union Geothermal

Drill sites at the Baca geothermal field

All in all, the Baca experience has been a sobering one for those in geothermal exploration. They are unlikely to underestimate again the unpredictability of complexly fractured, volcanic geothermal fields. But geothermal exploration will still be difficult at times. "I don't believe we have adequate tools for assessing and modeling volcanic fractures," says Martin Molloy, a review team member and DOE's Baca project termination manager in Oakland, California. "Our models [of reservoir structure and behavior] are not doing well because of fundamental shortcomings of understanding."

Those shortcomings are showing up at geothermal fields other than Baca. In Iceland, a 30-megawatt plant at Krafla is producing only 15 megawatts for lack of sufficient fluids. Problems of hot but scarce fluids have also plagued development of La Primavera field in Mexico. At Hatchobaru, the reservoir produces sufficient hot fluids, but drillers have not been able to find enough permeable zones to dispose of the waste water. At Kakkonda, reinjected waste water found an unexpected shortcut back to the production wells, decreasing power production until other reinjection wells could be drilled. Even at The Geysers, the United States' premiere geothermal field, success has reportedly been achieved by much trial and error drilling that eventually helped drillers learn how to locate producing zones more easily in the fractured volcanic rock there.

Technical problems may have technical solutions, as the oil and gas industry has often demonstrated. The trend toward initial installation of smaller power production units—10 to 20 megawatts rather than 50 megawatts—is giving drillers more time to deal with the technical problems of geothermal energy extraction. With Baca behind it and budget cuts making themselves felt, DOE has pulled out of all geothermal commercialization projects except one (at Heber in southern California) to concentrate on solving technical problems, including how to understand fractured volcanic systems. In the meantime, Union Geothermal is completing additional testing of the present wells at Baca in preparation for a return to exploration, rather than power production, at Valles Caldera.—RICHARD A. KERR

†G. S. Bodvarsson, S. Vonder Haar, M. Wilt, and C.-F. Tsang, *Water Resources Research*, in press.