Geothermal Tragedy of the Commons

Once a shining example for geothermal energy developers, The Geysers of northern California—the world's largest geothermal field—is rapidly running out of steam

IT WAS 1985 AND THE OUTLOOK FOR GEOthermal energy looked rosy—especially at The Geysers, a field of steaming fumaroles 115 kilometers north of San Francisco. The natural steam boiler beneath the Mayacamas Mountains had already made The Geysers "the largest complex of geothermal [electric] generating plants in the world," according to the brochure from Pacific Gas and Electric (PG&E), the utility that had begun exploiting it in 1960. To geothermal developers the world over, this field was a test case for the promise of cheap, smog-free energy from the earth's internal heat. The PG&E brochure suggested an almost limitless future: "Expansion [is] continuing steadily.... After 1990, The Geysers' total generating capacity is expected to be more than two thousand megawatts.... No definite estimate of ultimate capacity is possible."

Six years later, the promised expansion of The Geysers is over for good. Yes, The Geysers is supplying a hefty 6% of California's electric power and accounts for 75% of all the installed geothermal generating capacity in the United States. But the generators at The Geysers, which were built to produce the promised 2000 megawatts, are actually yielding only 1500 megawatts. Worse yet, steam pressure in the wells is plummeting. The underlying problem is simple: The earth beneath those northern California mountains is running dry. As a result, the outlook for The Geysers is grim: By the mid or late 1990s, power output may slip to half its 1987 level. A $3.5 billion investment is in danger of turning into a white elephant.

The underlying problem at The Geysers—and a danger for geothermal development everywhere—is overdevelopment of a poorly understood resource that was fair game for everyone. "Put simply, there are too many straws in the teapot," says Thomas Box of Calpine Corp. of Santa Rosa, one of the firms operating in The Geysers. For more than 25 years, the temptation to add yet another straw has been virtually irresistible. About all you had to do to get at the energy was drill a bunch of holes down into the steam-filled cracks of the reservoir rock, connect the drill holes to a power plant, and watch the electricity come out. By the late 1980s "it became obvious that there were too many plants," says Box; "the field was overdeveloped."

An oil man might have seen it coming—he'd be used to seeing fields peter out. But at The Geysers there is no foreseeable shortage of the energy resource—heat. An intrusion of molten rock that rose beneath the field within the past million years delivered all the heat geothermal developers could want. That heat has boiled ground water into steam at a pressure of 3.5 megapascals (34 atmospheres). In 1847 plumes of this steam leaking from the ground convinced The Geysers' discoverer that he had come upon "the gates of hell" itself. By the 1960s, geothermal energy developers saw instead a bonanza.

How big was the bonanza? Although no one really knew, optimism prevailed as everyone focused on the vast supply of heat but neglected the question of whether there was enough water to carry the heat to the surface. But through the 1960s, as new wells continued to be productive and seemed to be draining little steam from existing wells, a consensus developed that The Geysers could supply enough steam for 3000 megawatts of electricity—the equivalent of three large coal-fired plants, enough power for 3 million people. That withdrawal rate, it was predicted, could be maintained for at least 30 years—long enough to justify the construction of power plants.

Exploiting this promise through the mid-1970s was just one developer, Unocal Geothermal Division, which drilled wells and supplied steam to plants built by Pacific Gas and Electric. As a result, the pace of development was leisurely—an average of 70 megawatts of new capacity per year were installed in the 1970s. By 1981, there were 14 generating units dotting the field, with a total output of 943 megawatts.

If development had stopped right there, those power plants might still be running at full capacity. And that's not just the wisdom of hindsight: Even in the early stages some experts, including reservoir engineer Henry Ramey of Stanford University, warned that the steam reservoir might run dry much faster than developers hoped. Development, he said, should move cautiously.

Instead, changing economics had just the opposite effect. The success of the PG&E/Unocal team began to draw attention just as oil prices skyrocketed during the oil embargo. Then, to top it off, the federal government provided economic incentives beginning in 1980 to encourage the development of alternative energy sources such as geothermal. Development accelerated, jumping from 70 megawatts to 150 megawatts of new capacity per year as new steam suppliers and utilities operators entered the game. By 1988, generating capacity had more than doubled from its 1981 level, to 2043 megawatts, and the number of players had grown to five utilities, three developers, and three developer/utility combinations.

PG&E

Losing its lifeblood. *Power plant at The Geysers geothermal field.*

Overdevelopment did more than speed up the depletion of the field. With half a dozen development teams tapping the field instead of one, the news that steam pressures were dropping at an accelerating pace all across the field was slow to diffuse, and new plants kept being built. In some wells, the rate of decline increased as much as threefold in the 1980s. Steam delivery is dropping by 11% per year on Unocal leases, according to Benjamin Barker at Unocal. By 1987, power production peaked, then began nosing down.

Only now is it clear to everyone that there never was enough water in the rocks and crevices below the field to sustain the bonanza. Until now, there was no way to know for sure. In most other geothermal fields, drilling penetrates a layer of superheated water whose volume can be measured directly. But The Geysers produces straight steam no matter how deep the well, and steam provides no measure of the volume of water giving rise to it. Barker compares The Geysers reservoir to a boiling teakettle, which steams vigorously until it suddenly boils dry. "You don't know how much water you had until it's gone," he says.

But instead of proceeding cautiously, most planners assumed enough water was down there somewhere for their next project, and the California Energy Commission—which since 1975 had to approve each step in development—was always willing to be convinced. Ramey sums it up: "There's been a lot of wishful thinking."

It's probably too late to stop, much less reverse, the decline of The Geysers, but experts are scurrying to find ways of slowing it down. This week in Sacramento the Energy Commission heard testimony on means of conserving steam and operating the plants more efficiently, but for reservoir engineers the prime topic of interest was the possibility of rejuvenating the reservoir by injecting cold water into it.

Some injection is already going on. About 25% of the used steam is condensed before it is lost to the atmosphere and reinjected into the wells—an effort that has had mixed results. But a recent cooperative injection experiment involving several different producers at The Geysers suggests that in some places carefully thought-out injection procedures can reliably increase steam output. Even if they work, though, water is so scarce in the area of The Geysers that operators might have to pipe in treated sewage to recharge the field.

As scientists and engineers attempt to prolong the life of The Geysers, they are pondering what their experience there has to say about other geothermal fields. There's plenty more geothermal energy out there to be exploited, but developers may now be acutely aware that they're looking at a finite resource, to be exploited cautiously. David Anderson, director of the Geothermal Resources Council in Sacramento, speaks for most when he concludes: "The lesson from The Geysers is that until you really understand the reservoir, don't take anything for granted." ■ RICHARD A. KERR

The Back Burner of Geothermal Energy

Conventional geothermal energy is extracted from places where hot rock and ground water have come together naturally, providing a ready supply of superheated water or, as at The Geysers, steam (see main text). But as the experience at The Geysers is underscoring, there can be far more extractable heat just below the surface than there is ground water to carry it out. Efforts to develop techniques for getting at this additional geothermal energy have been on the back burner for much of the past decade, but the potential payoff is so huge that the work—largely funded by the Department of Energy (DOE)—continues.

■ **Hot dry rock.** Take the heat lingering near the surface in volcanic areas of the United States. In the hottest areas alone, it has been estimated that 430,000 quads of energy are within reach of drilling. That is about 10 times the heat energy of all U.S. coal deposits. No one expects to get all that heat out, but even a bit of it would be a big help.

Lacking the usual makings of a geothermal system—steam- or water-filled fractures—hot-dry-rock researchers have to create their own systems. They drill into hot rock, fracture it with high-pressure fluids, and pump water down into the fractures, where it picks up heat before continuing back to the surface through a second drill hole. Such a system was completed in the 1980s at Fenton Hill in New Mexico, but the difficulty of creating a large enough fracture system and mechanical problems in the wells hampered testing (*Science*, 27 November 1987, p. 1226). But now, final preparations are being made for a year-long flow test that should indicate whether the system can maintain its heat output without cooling off too fast or leaking excessively. After a promising 30-day flow test and a dramatic decrease in water losses due to leaks, DOE project manager David Duchane of Los Alamos National Laboratory is optimistic about the outcome of the long-term flow test, which will begin in September.

■ **Magma.** The ultimate geothermal energy source is not just hot rock; it's molten rock. At temperatures of 800°C to 1100°C, the magma bodies within reach of drilling in the United States are estimated to contain between 50,000 and 500,000 quads of thermal energy. No hardware durable enough to tap into these searing deposits exists yet, but engineers have tested some ideas in a lava lake in Hawaii. To make drilling practical, they chilled and solidified the magma ahead of the drill bit with circulating water. But the big heat repositories are magma chambers, which are thought to lie at depths of several kilometers beneath volcanic areas. In a pathfinding effort, the DOE is drilling in Long Valley, east of Yosemite National Park, trying to confirm geophysical predictions of a magma chamber lying 5 to 7 kilometers down. This summer the Long Valley well, begun in 1989, should reach a depth of 2300 meters. As more money becomes available, the goal is to reach a depth of 6 kilometers or a temperature of 500°C, whichever comes first.

■ **Geopressured energy.** Beneath the oil-rich Gulf Coast lies geothermal energy in still another variety, this one dependent neither on flowing ground water nor on volcanic activity. The geopressured energy deposits of Texas and Louisiana are a hybrid of geothermal energy and fossil fuel: reservoirs of hot, gas-charged seawater. The deposits formed between 15 million and 50 million years ago when seawater was trapped in porous beds of sandstone between impermeable clay layers. The water in turn trapped heat flowing from below as well as the methane released by the decay of organic matter. As more sediments piled on, the hot, gassy water became pressurized.

In the 1970s, a few energy researchers speculated that a simple drill hole into a geopressured zone would unleash a gusher of geothermal heat, with an added bonus in the form of natural gas. More than a decade of DOE-funded research has reduced optimistic early projections of the potential resource to a modest 5700 quads of methane and about 11,000 quads of thermal energy. The research also raised questions about the economics of geopressured energy. But DOE program manager Raymond Fortuna reports that a long-term flow test of a well in Louisiana has brightened the outlook again by showing that a single well can drain a far larger volume than had been expected, meaning fewer costly wells would be required to produce energy. Still, recalling the sobering example of The Geysers, researchers want to know why their drill hole seems to work so well before making claims for a new energy source. ■ R.A.K.