Mammoth Geothermal

A Development History

Richard Campbell Tells the Story of This Showcase Binary Loop Geothermal Facility in California

The Mammoth Geothermal Project is located within the Long Valley Known Geothermal Resources Area (KGRA) on the eastern slope of the Sierra Nevada mountain range of California, some 300 miles north of Los Angeles. Three miles west of the plant is the village of Mammoth Lakes, a well-known and rapidly growing winter and summer resort.

The Mammoth Geothermal Project consists of three binary cycle power plants, which use isobutane as the working fluid. Built in 1984, MP-1 (now G-1) generates 10 megawatts (MW) of power from two turbines; while the other two plants, MP-2 and PLES-1 (now G-2 and G-3), each generate 15 MW from three turbines. The latter two plants were built in 1990. Heat rejection from all three plants is via air-cooled heat exchangers.

This paper is an overview of the design of these three power plants, now owned and operated by Ogden pacific Power, Inc. The text is based on two references, which contain additional information and other references.

Power Plant MP-1

Ownership of MP-1 at the time of construction was by Mammoth-Pacific (MP), a joint venture of Pacific Energy Resources, Inc. (a subsidiary of Pacific Lighting Energy Systems, which was in turn a subsidiary of Pacific Lighting Corp. - Los Angeles) and Mammoth Binary Power Co. The general partner of Mammoth Binary Power Co. was Holt Geothermal Co., an affiliate of The Ben Holt Co. (Holt - Pasadena, CA), which designed the facility. Construction was by Kennebec Construction Co., a Holt subsidiary.

MP-1 consists of two identical, air-cooled binary cycle geothermal power plants. Net power production from each plant is about five MW during winter operation. Because the plant is air-cooled, power production is lower during the warm summer months.

The Reservoir. Eight geothermal wells were drilled on Magma's property and flow tested in the early 1960s. This early work demonstrated the existence of a reservoir of hot water at shallow depths (400 to 800 ft.). Reservoir temperatures averaged about 330°F, and total dissolved solids were about 1,500 ppm. Early test work involved free-flowing the wells for periods varying from a few days to weeks. Carbon dioxide was evolved during these tests, resulting in calcite formation in the wellbore. A shaft-driven downhole pump was used in subsequent test work to eliminate calcite formation by maintaining single-phase flow in the wells and surface equipment. Another advantage of using downhole pumps is that the brine stays at the downhole temperature rather than being cooled by flashing.

Power Plant Justification. In the early 1980s, nearly all residential and commercial space heating in the Mammoth Lakes area was electrical, served by the Southern California Edison Co. (Edison). Electrical usage at Mammoth peaks in the wintertime, unlike the rest of the Edison system. While some power is provided by hydro plants in the area, most of the Edison supply arrives via a transmission line connecting to Edison facilities in the

Air cooling towers at Mammoth Pacific Geothermal Complex near Mammoth Lakes, CA, built during the project's second phase of construction and capacity additions.

Mojave Desert some 200 miles to the south. The need to augment energy needs in the area by producing electricity from geothermal resources and using geothermal heat to replace electricity for space heating has long been recognized. Several developments led to the realization of the MP-1 power plant. They included:

- Increasing demand for electricity in the Mammoth Lakes area;
- Passage of the Public Utilities Regulatory Policy Act (PURPA), requiring utilities to purchase power at avoided cost;
- Utility interest exemplified by Edison's stated policy to develop 2,100 MW of alternative energy by the year 1990;
- Tax incentives providing for accelerated depreciation (5 years) and an effective investment tax credit of 25 percent; and
- Development of the concept of small, wellhead generating units, employing a standardized process design; use of off-the-shelf equipment; design for construction within a 12-month period; and capability of relocation to a new site.

Design Criteria. The following criteria were key elements in deciding upon MP-1 design:

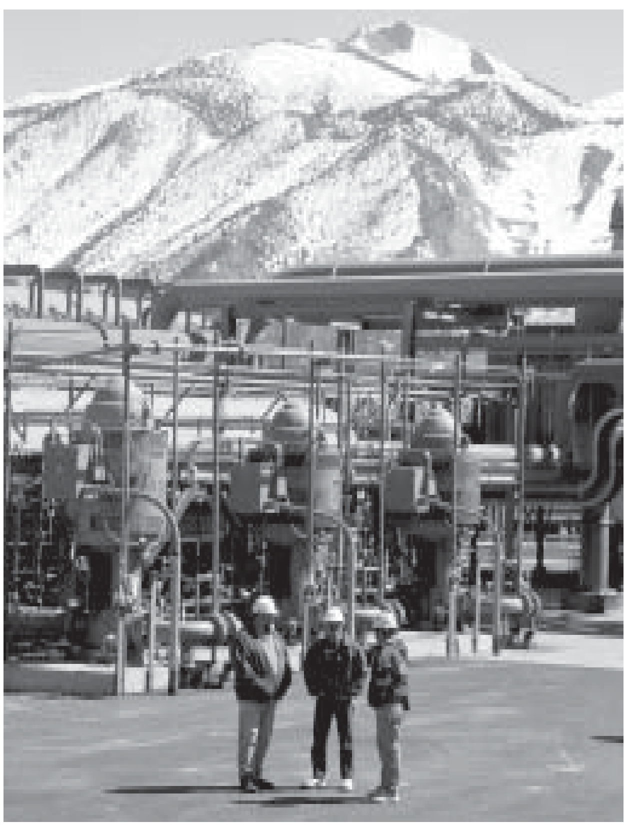
- The facility must be environmentally acceptable, because it is surrounded by U.S. Forest Service land in an area possessing great scenic and recreational value;
- To minimize construction costs in a remote area, the facility should employ modular construction techniques to the maximum extent possible; and
- To qualify as a baseload facility, it should be designed for high availability and reliability.

These considerations led to the choice of a simple binary cycle plant employing 100-percent air cooling. The geothermal fluid is maintained in a liquid state throughout, and 100-percent of the fluid is reinjected. Moreover, no cooling water is required in an area where fresh water is at a premium. Air cooling also permits taking advantage of cold air as a cooling medium particularly in the wintertime, thereby increasing thermal efficiency and power output by reducing condensing pressures during the season when electric power is most needed at Mammoth.

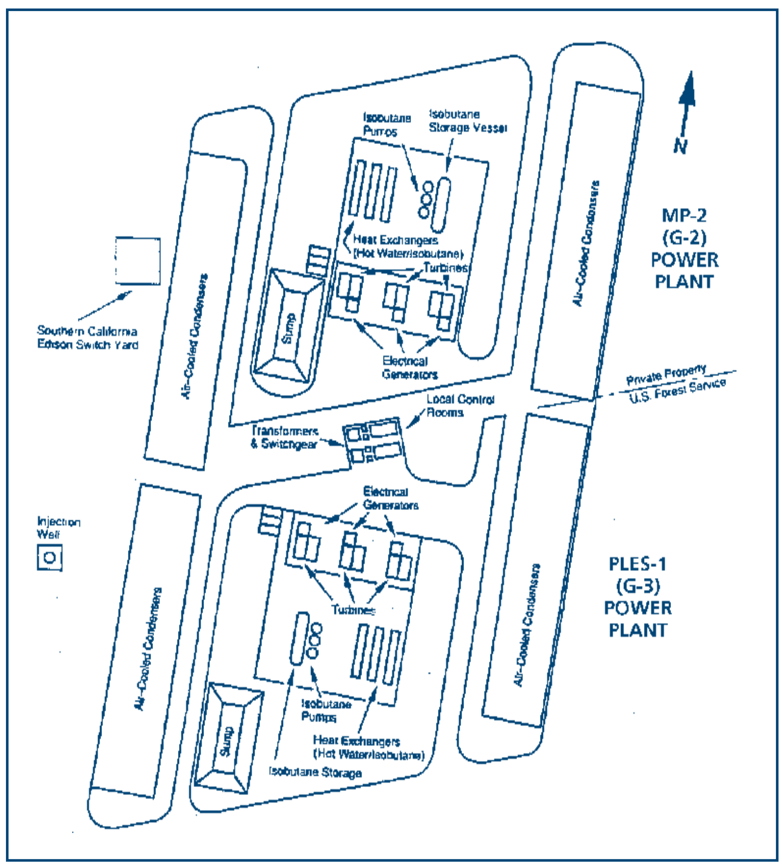
System Description. The facility is based on a Rankine cycle with isobutane as the working fluid. Vaporization is subcritical, though near the critical point. Condensation of turbine exhaust is in air-cooled heat exchangers. The design basis of each module is as follows:

- **Brine:** Temperature in–330ºF / Temperature out–150ºF to 180ºF, depending on ambient air temperature.
- **Working Fluid:** Composition–Isobutane / Turbine inlet–500 psia, 280ºF / Condensing temperature–70ºF to 120ºF, depending on ambient air temperature / Cooling–100 percent air.

Operation using the floating mode concept results in varying power outputs throughout the year, with output higher in cold weather



Ogden Power Pacific, Inc. Facility General Manager Jim Anderson (left) joins Mono County Energy Dept. Director Dan Lyster, and Plant Manager Bob Sullivan (right) on a tour of binary conversion facilities at the Mammoth Pacific Geothermal Complex.



Plan of Mammoth Pacific Geothermal Plants MP-2 (G-2) and PLES-1 (G-3). Illustration courtesy of Mammoth Pacific, Ogden Power Pacific, Inc.

Popular soaking holes abound along the scenic—and aptly named—Hot Creek, where hundreds gather at various times of the year to relax in its pools fed by streambed geothermal vents. Only a few miles away, Mammoth Pacific's Geothermal Complex has had no significant effect on Hot Creek or numerous hot springs in the area.

than during warm months. Total annual power output is higher using this concept than if a single, high air temperature was chosen as the design point for year-round operation. Geothermal brine is pumped from production wells and through heat exchangers using vertical lineshaft turbine pumps. Cooled brine leaving the heat exchangers is pressurized for reinjection by centrifugal pumps at the plant site.

Construction Materials. Carbon steel is the primary material of construction. It has been found to hold up well so long as brine is not allowed to be oxygenated.

Advantages of Small Power Plants. Small geothermal power plants, and in particular small binary plants ranging in the size from one to 10 MW, have a number of advantages compared to large plants (50 MW and up). Some of these advantages are:

- Time required for design, procurement and construction is relatively short, so capital is not tied up for a long time;
- Equipment is small enough that an entire plant can be moved from one resource to another if necessary;
- Multiple units of the same design and at the same location can use common spare equipment, resulting in lower initial investment and smaller inventory;
- A geothermal resource can be developed in stages at a low initial investment. Income from early development can finance later construction. This also allows system development to utilize operating data from early stages for refinement in design;
- Plants can be scattered throughout a well field, minimizing piping, or can be located in a single, central location to save on utility interconnections;
- Economies of scale are largely offset by the use of modular construction techniques, multiple purchases of major equipment, and by spreading design costs over multiple units;
- Components are state-of-the-art and readily available with little developmental cost;
- Small units minimize technical, institutional, and ultimately, financial risk;
- Multiple units provide high reliability; and
- Any mistakes made in the design of the power plant or assessment of the reservoir will be on a small scale.

Advantages of Modular Construction. The MP-1 design utilized modular construction techniques to the maximum cost-effective extent, thereby minimizing erection costs in a remote area and maximizing salvage value. Examples include:

- Each turbine-generator set is a single, skid-mounted unit, arriving in two pieces but erected on a single skid requiring minimum foundation support (the lube oil cooler is a separate, third skid);
- Electrical switchgear was shop fabricated and shipped to the job as a single unit;
- Air cooling sections are mounted on steel structures (both air coolers and structures could be dismantled for shipment to a new site); and
- A large part of the piping was shop fabricated.

Power Plants MP-2 and PLES-1

The MP-1 power plant operated successfully for six years prior to the construction of the new plants, and provided incentive for expanding the project. Ownership of MP-1 was by Mammoth-Pacific, a partnership between Mammoth Binary Power Co. and Pacific Energy (known at that time as Pacific Lighting Energy Systems). Pacific Energy later acquired total ownership of MP-1, and undertook to build additional units. Obtaining permits for construction of the new units took more than three years. Final approval was obtained in August 1989, when a fast-track design, procurement and construction effort was begun. Two power plants of nearly identical design make up the expansion at Mammoth. MP-2 is on land leased from Magma Energy, Inc., the same company that owned the land MP-1 is on. The other new plant was PLES-1, for Pacific Lighting Systems Unit 1, and situated on land leased from the U.S. Forest Service.

Project Participants. Pacific Energy, a subsidiary of Pacific Enterprises, was plant owner and operations manager. Constellation Energy was Pacific Energy's partner for the expansion. Design and procurement were performed by The Ben Holt Co., which also provided support services during construction, start-up and testing. The Industrial Co. (TIC) was construction contractor for the project. Initial operation was by North American Energy Services Co. (NESCO). Pacific Energy sold its interest in all three plants to Ogden Power Pacific, Inc. in 1997. Power is sold to Southern California Edison Co.

Permitting. Obtaining permits for building the new plants was a long and difficult process, despite the successful operation of

Showcase of Geothermal Development

Lying tight to the ground on a flat above U.S. Hwy. 395, its dull forest color shadows its impact on the surrounding scenery. Frequently missed by tourists and even local residents as they pass by, the Mammoth-Pacific binary power plants outside Mammoth Lakes, CA quietly and efficiently produce approximately 40 megawatts of clean geothermal energy for the burgeoning "green" power market.

Owned and operated by Ogden Power Pacific, Inc., the Mammoth facility is clean, trim and exacting in its layout—and a true showcase of geothermal power development—set against a backdrop of spectacular Sierra Nevada peaks. Facility General Manager Jim Anderson, who has managed the operation for nearly a decade, notes with pride that the Mammoth power plants are tapping a truly renewable geothermal resource. "Reservoir pressure has remained steady throughout the life of the facility," he says.

The geothermal power plants at Mammoth have proven themselves a good neighbor, as well. "We have an excellent relationship with the community of Mammoth, and with local government agencies," says Mammoth Plant Manager Bob Sullivan. He'll find no disagreement with Mono County Energy Dept. Director Dan Lyster. "Mammoth-Pacific is a true success in nearly every sense of the word," he says. "The county, federal and state government experience with the power plants has been a good one, with excellent communication and similar concerns for the community and the environment."

Indeed, the California Department of Fish & Game has worked closely with facility management to monitor for any possible cooling of the geothermal reservoir that might affect a nearby fish hatchery's water system. "The Mammoth plants have posted no significant effect in reservoir temperature since operations began, and energy extraction hasn't affected Hot Creek and the numerous other hot springs in the area," says Lyster. (TJC/CRC)

MP-1. A major obstacle was opposition to industrial development by local residents in and around Mammoth Lakes, a year-round resort area. Detailed plans were prepared for spill containment, emergency shutdown, fire protection, grading, landscaping and revegetation. In addition, a concerted effort was made to minimize visual impact by designing the plant with a low profile, painting to match surrounding vegetation, and providing minimal lighting at night. Also, trees were transplanted to block the view of the plant from a nearby highway. Through these efforts, support from the Mono County Board of Supervisors was won and a negotiated settlement with various intervenors was achieved.

Process Design. The process design for the new power plants was based on the design successfully used for years in MP-1. A subcritical binary cycle with isobutane as the working fluid is utilized to efficiently generate power from the geothermal brine. Air-cooled condensers are used to take advantage of low ambient temperatures at Mammoth, and to provide a system design with minimal environmental impact. Design conditions for the working fluid and geothermal brine are similar to those at MP-1. Geothermal brine is pumped from production wells and through heat exchangers using vertical turbine pumps. Brine is kept under pressure throughout the process, thus maintaining the brine as a liquid and avoiding problems of two-phase flow, noncondensable gas breakout, and calcite formation due to flashing. Cooled brine leaving the heat exchangers is at high enough pressures for injection back into the ground. Injection pumps have been provided in case required injection pressure increases during the life of the plant. One significant design change from MP-1 is that each of the new plants has three turbines in parallel, using common pumps, heat exchangers and condensers. By having three turbines in parallel, the new plants are able to continue operation at a high level, even if one of the turbines is off-line. Since the other two turbines are able to generate more power by operating with a higher isobutane flow, loss of one turbine reduces capacity by less than one third. At MP-1, each of the two turbines has its own set of pumps, exchangers and condensers, so the loss of one turbine means that half the capacity is lost. Power output from each new unit exceeds 15 MW during cold weather. When combined, sales are more than 40 MW from MP-1, MP-2 and PLES-1.

Equipment Selection. Equipment used for the new plants is much the same as for MP-1. Carbon steel was used as the primary material of construction for both the brine and isobutane loops. Three radial inflow turbines for each plant were provided in skid-mounted packages with lube oil systems and speed reduction gears. Synchronous generators were shipped separately, and added to the turbine skids in the field. The air-cooled condensers are large pieces of equipment. Each plant has 40 air cooler bays, each 14 feet wide by 60 feet long, with three 13-foot diameter fans. Heat is transferred from the brine to the isobutane in six shell-and-tube exchangers per plant. The exchangers are piped in three sets of two shells, allowing any pair of shells to be blocked in for maintenance while operation continues with the remaining shells. Geothermal production pumps are lineshaft driven, vertical turbine pumps. Four production pumps per plant were installed, although only three are required for normal operation. Brine injection pumps are horizontal centrifugal pumps. Each plant has two injection pumps, piped so either pump can run independently, can run together in series, or allow complete bypass. Isobutane is circulated through each plant by three vertical canned pumps. A distributed control system (DCS) allows the new plants to be operated from the MP-1 control room. However, enough local instrumentation and controls were installed to allow the plants to be started up and operated without the DCS.

Construction. Grading work began early in 1990, but construction did not begin in earnest until April 1990, due to the harsh winter weather at Mammoth. Work crews generally did their work first on MP-2 then moved to PLES-1. MP-2 reached mechanical completion in late November, and PLES-1 was complete by mid-December 1990. Follow-up work such as painting and fireproofing was completed in January 1991.

Start-Up. Initial turbine roll in MP-2 occurred on Dec. 3, 1990. Operation of the other turbines followed in ensuing days. Minor problems were detected during start-up of MP-2, and solutions to these problems were simultaneously implemented in both MP-2 and PLES-1. By Dec. 22, 1990, both plants were on-line, with all six turbines running and power being sold to the Southern California Edison grid.

Operation. During January 1991, operation continued while a shakedown of all equipment and controls was conducted to prepare for performance testing. A 30-day performance test was begun on Feb. 9, 1991, and was successfully completed by both MP-2 and PLES-1. Both plants have remained in full-time, commercial operation since the conclusion of the performance test. MP-1, MP-2 and PLES-1 have all achieved high availability and capacity factors throughout their operating history. ■

References

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During his 23 years with The Ben Holt Co. (Pasadena, CA), **Richard Campbell** was process engineer and project manager for several geothermal power plants, including binary cycle facilities at Mammoth (California) and Steamboat (Nevada), and at the U.S. Department of Energy's hybrid-cycle demonstration plant at the Pleasant Bayou (Texas) geopressured resource. As president of Holt from 1994 until May 1999, he led design of the 165-megawatt (MW) Mahanagdong geothermal power plant in the Philippines, and the 55-MW Dieng geothermal power plant in Indonesia. Campbell served as president of the Geothermal Resources Council (1995-96), as a director of the International Geothermal Association, and as chairman of the Southern California Section of the American Institute of Chemical Engineers. He holds bachelors (University of California Davis) and masters degrees in chemical engineering (Caltech). Campbell left the Ben Holt Co. in early 1999, and subsequently took a position as Manager of Technical and Engineering Services with TIC-The Industrial Co. (Steamboat, CO). He can be reached by e-mail at:<rcampbell@ticus.com>.