# Geothermal California

## California Claims the World's Highest Geothermal Power Output, With Potential for Even More Production With Advanced Techniques

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*Figure 1. Shaded relief map of California showing major physiographic-tectonic provinces, locations of geothermal power plants, and zones of elevated heat flow (>100 mW m$^{-2}$, hachured areas). Abbreviations are: Glass Mountain (GM), Surprise Valley (SV), Honey Lake (HL), and Long Valley (LV).*

California contains, by far, the greatest geothermal generating capacity in the United States, and with the possible exception of Alaska, the greatest potential for development of additional resources. California has nearly two-thirds of U.S. geothermal electrical installed capacity of nearly 3,000 megawatts (MW). Depending on assumptions regarding geothermal reservoir characteristics and future market conditions, additional resources of between 2,000 and 10,000 MW might be developed (Muffler, 1979). However, current industry estimates are nearer the lower number.

High-temperature geothermal resources are distributed unevenly across the state. The map accompanying this article shows locations of existing power plants (solid stars) and projected or planned developments (open stars), together with areas characterized by heat flow greater than 100 mW m$^{-2}$ (hachured areas). A detailed U.S. Geological Survey Heat Flow Database for California (Williams, 2001) is accessible on the Internet at: http://proto-dev.wr.usgs.gov/heatflow/index.html.

Regions characterized by these high heat flows are more likely to contain the relatively rare areas where temperatures of >150°C at depths that can be drilled economically (currently about 3 kilometers, or 10,000 ft). Most geothermal power plants are associated with areas of young-to-contemporary igneous activity (one million years old or younger).

According to the California Energy Commission, the state has 46 geothermal plants with a total installed electrical capacity of 2,561.7 MW (Table 1). For most sites, installed capacity is very close to the power output from the field. The Geysers is an exception, with a contemporary generating capacity of about 1,000 MW. Thus, *actual* generating capacity of California geothermal plants is about 1,800 MW, rivaled only by the Philippines. Additional information on California geothermal power generation is available on the DOE renewable energy web site at: www.eren.doe.gov/geothermal.

*Table 1. Installed Capacity (MW) of California Geothermal Plants, 2001*

| Area | Plants | Capacity |
|---|---|---|
| Amedee/Wineagle (HL) | 2 | 2.3 |
| The Geysers* | 21 | 1,807.6 |
| Long Valley (LV) | 4 | 37.0 |
| Coso | 4 | 240.0 |
| Imperial Valley | 16 | 474.8 |
| **TOTALS** | **46** | **2,561.7** |

* Total generating capacity of The Geysers plants is currently less than 1,000 MW

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*The Geysers is the world's largest-capacity geothermal field. The Geysers' 21 power plants are operated by Calpine Corp. and the Northern California Power Agency.*


Steve Burden / Calpine Corp.

*Construction of the Santa Rosa Geysers Recharge Project should allow 100-percent replacement of produced steam, ensuring continuity and sustainability of The Geysers Geothermal Field.*

## Glass Mountain

Glass Mountain is a part of the Quaternary Medicine Lake Volcano. It has been the subject of intensive geologic study (Donnelly-Nolan, 1988, 1990, and others) and considerable geothermal exploration (Hulen and Lutz, 1999). There is demonstrated potential for geothermal power development, but a combination of market conditions, environmental issues, and Native American tribal concerns has slowed progress toward realizing it. Resolution of some of these issues has led to plans for renewed exploration and development by Calpine Corp. (San Jose, CA).

Presently, Calpine is planning to build a 49.5 MW power plant in the northwest section of the Glass Mountain Known Geothermal Resource Area (KGRA). The Fourmile Hill Project has obtained all necessary federal and state environmental permits to allow steam field and power plant development, and a geothermal exploration program is in progress to confirm the extent and production capability of the resource in the project area. If this program is successful, the Fourmile Hill Project could be on-line by December 2004.

Calpine also plans to build a second 49.5 MW power plant, the Telephone Flat Project, in the southeast section of the Glass Mountain KGRA, east of Medicine Lake. This project was acquired from CalEnergy in October 2001. Federal environmental permits for the Telephone Flat power plant and geothermal field development were denied by the U.S. Bureau of Land Management (BLM) in May 2000, prior to Calpine's acquisition. The company has convinced the agency to reevaluate the project's impact to the Glass Mountain area, and seeks a reversal of BLM's original decision by November 2002. Calpine hopes to have the Telephone Flat Project on-line by December 2005.

## Surprise Valley and Honey Lake

Surprise Valley also has well-documented potential for geothermal power development, on the order of several tens of megawatts. The Bonneville Power Administration (BPA - Portland, OR) expressed interest in geothermal power production from the area as part of its energy diversification process a decade ago. However, expected costs of wheeling electricity from Surprise Valley north to the BPA grid resulted in a cancellation of the project. The Amedee geothermal plant near Honey Lake has contributed an average 1.6 MW of electricity to the California grid since October 1988. Another 0.7 MW is produced at the nearby Wineagle geothermal power plant.

## The Geysers

The Geysers Geothermal Field has been the world's largest producer of geothermal electrical power since the 1970s. It reached a peak of over 1,600 MW in 1987. This level could not be sustained, however, because reservoir pressure drops resulted in rapidly declining power production over the ensuing decade. Power plant operators augmented injection of condensate with local surface water, but substantial slowing and stabilization of pressure declines was not accomplished until the successful completion of the Southeast Geysers Effluent Pipeline (SEGEP).

Dedicated on October 16, 1997, the world's first wastewater-to-electricity system has had a dramatic effect on sustaining the productivity and prolonging the life of The Geysers Geothermal Field. A 29-mile pipeline carries 7.8 million gallons per day of make-up water from Clear Lake and treated effluent from sewage treatment plants in Lake County, CA to injection sites within the field.

Today, The Geysers' 21 power plants are operated by Calpine Corp. (19 facilities) and the Northern California Power Agency (2 facilities). Inefficient power plants have been retired, and others are being reconfigured to operate efficiently with lower pressures offered by the geothermal reservoir. Even with the success of the SEGEP project, current generating capacity at The Geysers is less than 1,000 MW. But that figure will rise with completion of a second pipeline to the geothermal field. Project partners say the Santa Rosa Geysers Recharge Project should allow 100-percent replacement of produced steam, assuring continuity and sustainability in Geysers power production.

Construction of the Santa Rosa Geysers Recharge Project is on schedule, and the City of Santa Rosa and Calpine hope to complete the pipeline by the end of 2002. The project includes a 40-mile pipeline from the city's Subregional Wastewater Treatment Plant to the southern edge of The Geysers, where Calpine is building a distribution pipeline to various injection wells within the field. When completed, the $210 million system will deliver 11 million gallons of tertiary treated wastewater per day to The Geysers. It is expected to generate enough steam in the reservoir to produce an additional 85 MW of electricity. The 1998 project agreement between Santa Rosa and Calpine has a 30-year term, commencing when the facilities begin operation.

Santa Rosa has six active contracts for construction of seven different segments of the pipeline. The first 30 miles is 48-inches in diameter, to ensure additional capacity for future irrigation projects in northern Sonoma County. The last 10 miles is 30-inches in diameter, and includes three pump stations that will lift the water 3,300 ft to the Geysers. The city had completed 21 miles of the pipeline, and its pump stations were more than 50-percent complete at the time of this writing (mid-summer 2002).

Calpine had built over 13 miles of pipeline and connected to the Santa Rosa's termination reservoir by early July 2002. The company had also completed construction of their 16-million gallon-per-day pump station and one-million gallon distribution tank. With a connection to SEGEP, Calpine will operate their new pump station to distribute Lake County water to the northern portions of The Geysers steam field to test their new injection wells. Calpine is also building an 11-mile, 21-kilovolt transmission line to Santa Rosa's three pipeline pump stations. The line will deliver eight MW of power to lift the city's wastewater to The Geysers.

## Long Valley - Casa Diablo

The Mammoth-Pacific geothermal power plants at Casa Diablo on the eastern front of the Sierra Nevada Range rely on binary conversion of ~160°C water from an outflow plume related to Holocene volcanic activity in the west moat of the Long Valley Caldera. A total of 37 MW is produced from three binary power plants (Campbell, 2000). Despite evidence for magma intrusion related to the uplift of the resurgent dome of the caldera since 1980, no associated hydrothermal activity has been discovered.


***The Mammoth-Pacific binary power plants are in tune with their surroundings and the local community. Efforts are underway to increase facility efficiency and to expand operations.***

Currently, Mammoth-Pacific is exploring for new geothermal resources two to three km west of its existing well field. The company also has long-range plans for exploring the west moat of the caldera. The latter resource is far deeper than at Casa Diablo (~1,000m compared to ~200 m) but indications are that temperatures of geothermal fluids there may be 200° to 225°C.

Issues surrounding potential development of these areas include impact on temperature and pressure in Mammoth-Pacific's existing well field. Areas of new exploration are in the upgradient direction, and any fluid extraction in those areas could adversely affect existing well field production capacity. For more information on recent development activities and exploration by Mammoth Pacific, refer to "Exploring the Possibilities," in the July/August 2002 issue of the GRC *Bulletin*.

## Imperial Valley - Salton Sea

Hydrothermal activity in the Imperial Valley is associated with crustal extension and magmatism from a buried spreading center related to the East Pacific Rise. The San Andreas Fault begins north and west of this feature. There are currently three centers of geothermal production in the valley.

CalEnergy Operating Corp. (Calipatria, CA - a subsidiary of MidAmerican Energy Holdings - Omaha, NB) owns all of the power plants in the Salton Sea Geothermal Field, which contains the region's hottest and most saline brines. CalEnergy currently produces over 340 MW from their geothermal power plant Units 1 through 5. CalEnergy plans to increase production by 185 MW with construction of Unit 6, which will be the largest geothermal

CalEnergy Operating Corp. currently produces over 340 megawatts from their geothermal power units 1 through 5 near the southern shores of California's Salton Sea.

Photos: TJC / GRC

Planned improvements by East Mesa projects buyer ORMAT Nevada, Inc. will enable the projects to produce 25 percent more electricity for the California power grid.

power plant in the world. The company filed a permit application with the California Energy Commission in July for construction of the new power plant, and has executed a $2-billion, 20-year power sales agreement with the Imperial Irrigation District for 85 percent its energy output. CalEnergy has also built a $400-million facility to extract up to 30,000 metric tonnes of zinc per year from spent geothermal brines at its Salton Sea geothermal power plants.

About 80 MW of electricity is produced at the nearby Heber Geothermal Field by Covanta Energy (Fairfield, NJ), with a double-flash geothermal power plant and the Second Imperial Project binary unit (Sones and Schochet, 1999). ORMAT Nevada, Inc. (Sparks, NV) recently acquired geothermal projects at East Mesa, including the Ormesa I, IA, IE and II binary power projects, as well as the Geo East Mesa (GEM) I and II double-flash power projects. These facilities have a total capacity of 107 MW.

The Ormesa geothermal power plants are currently producing approximately 47 MW for sale to Southern California Edison under 30-year power purchase agreements, and one of the GEM power plants (neither of which have power sales agreements,) is producing pumping power for the Ormesa projects. ORMAT, which replaced the previously multiple resource and power plant owners, is managing the entire East Mesa resource for optimum utilization, replacing or refurbishing older, less efficient generating units and auxiliary equipment. When this work is completed in 2003, the East Mesa projects will be able to produce 25 percent more electricity for sale to the California power grid.

## Coso Geothermal Field

Located within the China Lake U.S. Naval Air Weapons Station near Ridgecrest, CA, power plants at the Coso Geothermal Field are currently operated by Caithness Energy, LLC (Reno, NV). The field's reservoir is in a Mesozoic granitic/metamorphic complex underlying the Quaternary Coso Volcanic Field. It currently produces 270 MW from four geothermal power plants. More than 100 wells have been drilled throughout the field, with production depths from 2,000 to 12,000 feet, and temperatures from 200° to 350°C.

Coso began generating electricity in 1987. Since then, improvements have resulted in more efficient use of the resource. Together with an annual drilling program, these improvements have helped keep the geothermal field producing far above its contract capacity of 210 MW. Future improvements to the field's injection system, injection augmentation, and relocation of injection fluids to mine heat from the margins of the resource (where there are high temperatures and low permeability) will help sustain the Coso resource well into the future. The latter effort is the subject of a DOE-sponsored multidisciplinary study led by the University of Utah's Energy and Geosciences Institute. For more information on the Coso Geothermal Field and its power operations, refer to "Model for Success," on page 186 of this issue of the GRC *Bulletin*.

## Future Prospects

Power plant developers typically aim for an economic life of 20 to 30 years for a given geothermal resource. Some facilities in California are early in this cycle, while others suffer from declines in temperature and pressure. The productivity and longevity of most geothermal resources can be increased through the application of Enhanced Geothermal Systems (EGS) technologies. These include improved energy conversion; directional drilling and targeted hydrofracture based on studies of regional and local stress fields; targeted injection using available surface water (including reclaimed waste water) and groundwater; and chemical treatment to mitigate the effects of scaling and corrosion.

At Coso, a DOE-funded project is testing EGS technology to mine heat from the impermeable, high-temperature margins of the field. The high permeability of the production area at Coso makes managing injection recharge difficult. However, low permeability wells drilled at the margins of the geothermal field have been successfully used for low-rate injection to provide reservoir support. The Coso EGS project will test a producer-injector pair, with the injection well thermally and hydraulically stimulated to improve injectivity. Tracer testing will determine the amount of connection between the producer and injector.

A recent report (Heavner and Churchill, 2002) projects growth of geothermal generating capacity in California of about 1,500 MW by 2010. Some of this growth will occur at new sites like Glass Mountain and Surprise Valley, and some by expansions and enhancements of existing facilities. The hachured areas of the map accompanying this article show areas not presently exploited for geothermal power production. They provide a number of good candidate sites for further exploration and evaluation. Some of these sites lie in environmentally sensitive areas (e.g. Mt. Lassen and Death Valley), and will probably never be developed. Substantial potential for augmenting resource production in California exists at currently producing geothermal fields, however, and is now being vigorously pursued through the application of various EGS techniques.

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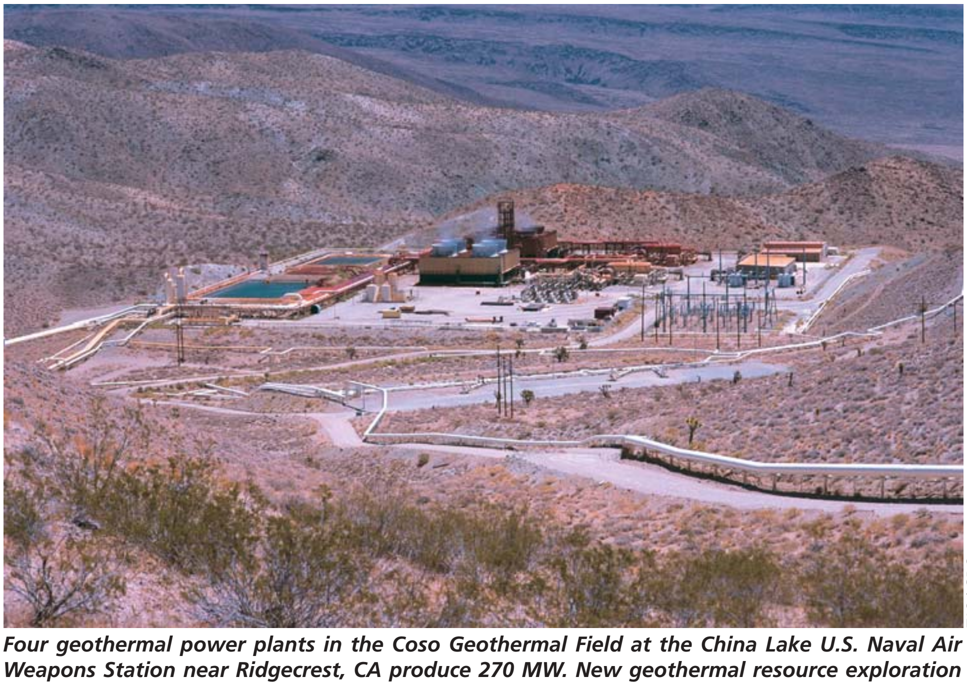

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***Four geothermal power plants in the Coso Geothermal Field at the China Lake U.S. Naval Air Weapons Station near Ridgecrest, CA produce 270 MW. New geothermal resource exploration may result in even greater power production in the future.***