BARRIERS TO FURTHER DEVELOPMENT OF HYDROTHERMAL ELECTRICITY GENERATION IN CALIFORNIA

Valentino M. Tiangco and Kelly Birkinshaw
Research and Development Office, Energy Technology Development Division,
California Energy Commission, Sacramento, CA. USA

SUMMARY

The constraints to further development of hydrothermal electricity generation in California are identified in this paper. These include the major environmental, technical, and economic barriers for further development of vapor-dominated and liquid-dominated (flashed steam and binary cycle) geothermal resources.

1.0 INTRODUCTION

In California, the total electrical generating capacity from geothermal resources is approximately 2,553 MW_{net}. A majority of this development has occured at the Geysers resource area. Approximately 690 MW_{net} has been developed using liquid-dominated geothermal resources in the areas of Coso Hot Springs, Imperial Valley, and Mono/Long Valley.

Three distinctly different technologies are used to generate electricity from these resources including, direct use of geothermal steam, binary cycle, and flashed steam. By technology, this study identifies the major environmental, technical, and economic barriers to further development of these resources in California.

2.0 VAPOR-DOMINATED GEOTHERMAL RESOURCES

Reservoirs containing superheated steam (392°F (200°C)) are quite rare. These reservoirs have proven to be economical to develop for electricity generation.

The Geysers Known Geothermal Resource Area (KGRA) is the largest developed vapor-dominated geothermal system in the world and the only such known resource in the United States. There are several constraints associated with the geothermal development at The Geysers. The magnitude of each one of these constraints is both site specific and cumulative.

2.1 Environmental Barriers [2]

2.1.1 Air Pollution

The Geysers contains a number of pollutants that are released to the atmosphere during operations which include hydrogen sulfide (H_2S), particulates and sulfates. Other pollutants which have potential health effects include arsenic, ammonia, benzene, boron, mercury, radon-222, silica, and vanadium.

Emission of H_2S exhibits a "rotten egg" odor at low concentrations and toxic at high concentrations. It can be controlled by external abatement systems that "scrub" the steam before it enters the turbine as well as the condensate when it exits the turbine and before it enters the cooling towers. The most common H_2S abatement systems include the Stretford system (for non-condensible gases) and hydrogen peroxide secondary abatement system (for condensate). Injection of hydrogen peroxide into the vented system is being done to control emissions of H_2S during drilling operations. Steamfield operations also result in H_2S emissions when the power plant is shut down and steam is stacked (vented) to the atmosphere. H_2S emissions from stacking are controlled by using automatic well throttle controls and interties between units or with a turbine bypass, which channels steam around the turbine to the condenser and subsequent abatement systems.

In addition, the evaporative cooling systems, typical of plants at The Geysers, release chemicals which have been added to the condensate to reduce corrosion, scaling, and the growth of algae and bacteria. These compounds, which include chromates, chlorine, and acids may potentially cause significant public health impacts.

2.1.2 Water Pollution

Construction of roads, well pads, and power plants, can accelerate erosion which increases stream turbidity and sediment deposition. In addition, spills from power plant and field operations have been a source of stream water quality degradation. Recent changes in plant operation practices and controls, however, combined with a reduction in the quantity of transported hazardous materials, have reduced the number of spills[2].

Elemental analysis was conducted on rainbow trout and Sacramento sucker muscle tissue from two streams in The Geysers area [5]. Specimens were collected in Big Sulphur

Creek from sites downstream and upstream of geothermal power facilities and in Little Sulphur Creek which has no nearby geothermal development. In comparison to freshwater fish from other geographic locations, those in The Geysers area show high levels of the potentially toxic elements, namely; mercury, lead, zinc, and copper (up to 0.7, 9.5, 47.3, and 3.1 ppm, respectively). In general, the data suggest that elevated elements level are characteristic of both Little Sulphur Creek and Big Sulphur Creek, however, zinc, copper, and lead are statistically higher in suckers collected downstream of geothermal development. Mercury is probably of greatest concern since mercury is known to bioaccumulate, which means that this heavy metal is transferred and concentrated in the food chain. There are critical thresholds in the physiology of all the species and in the ecological balance of the aquatic community. Trout and non-game species of fish have probably adapted to many of the environmental extremes of Big Sulphur and Little Sulphur creeks. Because of these extremes, the Big Sulphur Creek drainage is a stressed environment. Whether geothermal power development adds significantly to the stress is not clear. Further studies and monitoring will be necessary to adequately answer this question.

2.1.3 Waste Disposal

The most toxic wastes are generated from the operation of air pollution abatement systems. All hazardous and designated geothermal wastes must be transported great distances for disposal, adding to operational costs and increasing the risks of spills. Sulfur sludge accumulates in geothermal power plant cooling tower basins during normal operation. The use of Larox vertical chamber filter press has increased sulfur cake dryness from 50% - 58% to 68% - 72% solids by weight. Since the cake from the filter press is hard and brittle, more of it can be packed into the bins. For these two reasons, the volume of waste shipped from The Geysers to hazardous waste landfills has been reduced by about two-thirds [4].

2.1.4 Noise Pollution [2]

Natural ambient noise levels in The Geysers region are consistent with areas that are predominantly uninhabited and rural. Geothermal activity has caused the ambient levels to be raised in many areas. Geothermal development has two characteristics that result in special noise problems: the resource must be extracted and used near its source and technologies for noise control are not directly transferable from other industries. The closest operational analogy would be drilling under a controlled blow-out in natural gas fields. Only a few residents live within the area immediately affected by noise from geothermal activity in Sonoma County. A much denser population is adjacent to The Geysers in Lake County, which also is affected by noise resulting from geothermal activity in Sonoma County. Actual noise complaints filed in Lake County have risen steadily from a low of 51 in 1981 to a high of 331 in 1986.

Noise limits and requirements to use the best available control technology (BACT) for noise abatement, are generally dictated by the local county through use permits. Generally, as geothermal development moves closer to sensitive receptors, the required performance levels and costs of BACT will increase proportionately.

2.1.5 Destruction/Disturbance of Habitat [2].

Habitat loss, both temporary and permanent for Geysers units 1 - 18, was reported to be about 1,150 acres (460 hectares), or 11.5 percent of the total steam supply leasehold area. The percentage of cleared leasehold ranged from 8.4 to 24.0 percent. Most of the habitat loss was due to steam supply development, with 87.7 percent of habitat loss attributable to roads, wellpads, and steam lines. Habitat loss appears to be significantly reduced by the practice of directional drilling of multiple wells from a single well pad.

Due to the presence of several unusual combinations of geologic, topographic and micro-climatic conditions, there are an unusually high number of plants of special management concern in The Geysers region. Specifically, twenty-one plant species, subspecies, and varieties are considered rare, endangered, threatened, or candidates for listing and are protected to various degrees by the California Native Plant Society (CNPS), California Department of Fish and Game (CDFG), or the U.S. Fish and Wildlife Service (USFWS). Various wildlife species are also protected in The Geysers region including the endangered peregrine falcon and bald eagle, the threatened California yellow-billed cuckoo, and the fully protected golden eagle, ringtail, and black-shouldered kite.

The potential for such alteration to conflict with natural scenic qualities is increased by engineering and economic factors that often argue for the siting of geothermal facilities at visually prominent locations (e.g., ridgelines). Methods available for reducing these conflicts include minimizing cuts and fill, contouring with natural topography, clustering wells on single well pads, routing pipelines along roads, painting facilities natural colors, and using vegetation for screening.

2.2 Technical Barriers

2.2.1 Availability of Fuel or Resource [1, 2]

Since 1960, The Geysers has become the premier geothermal development in the world. However, in the mid-1980s, The Geysers reservoir has begun to exhibit the effects of heavy steam withdrawal. Steam pressure, particularly in the central part of the reservoir, has dropped much faster than was originally expected. In many existing wells, steam pressure has declined from the initial 500 psi in 1960 to less than 200 psi, shortening their useful life and hastening the need for make-up wells. But, in many instances, the additional supply of steam provided by new make-up wells has proven to be insufficient to maintain the original steam output. Also, many of the steam developers are encountering production interference. That is, steam that would otherwise be produced from an existing well is diverted to a new well.

The result of these effects has been a dramatic decline in output from many of the plants at The Geysers. Since 1986, electricity production has fallen by as much as 20 percent. The forecasts of future production from The Geysers also has fallen significantly. By 2009, electrical generation capacity is projected to be 1,025 MW, nearly one-half of the current capacity. Current estimates suggested that less than 5 percent

of the reservoir heat has been extracted from the Geysers KGRA.

Operational changes have become necessary to efficiently utilize the remaining steam reserves at the Geysers. The operational strategy which have been implemented to conserve steam reserves is load following. Load following involves planned lowering of the rate of steam extraction during predetermined parts of the day. Load following reduces the total amount of steam withrawn while delivering power at peak demand levels. Plants are throttled back during off-peak hours and returned to high output during peak periods. This strategy allow steam pressure to rebuild and result in an estimated 10 percent increase in available capacity, compared to ordinary baseload operation. Thus, this strategy acts to extend the life of the reserves and maximizes income by selling at the most advantageous prices.

Northern California Power Agency (NCPA) voluntarily reduced its annual load in 1988 by changing from base load to load following operations [1]. Output was reduced from 246 MW (gross) to an annual average of 150 MW (gross); however, the peaking capacity remains 246 MW (gross). NCPA attributes a reduction in well productivity decline rate from 24 percent to 16 percent to their load following efforts. Other field operators have analyzed the feasibility of implementing load following on an experimental basis, but NCPA remains the only plant where this generation strategy has been adopted as a routine practice.

In an attempt to understand how to respond in field pressure at the Geysers, the California Energy Commission appointed a blue-ribbon technical advisory committee (TAC) to study the problem and make recommendations to correct the situation. In 1990, the committee reported that the reservoir was not being naturally recharged with sufficient groundwater necessary to maintain current steam withrawals (production levels). Two recommendations were made: (1) artificially recharge the reservoir by injecting surface water, or (2) permanently curtail steam production. California at present is in the midst of a serious drought, and regional water supplies may be too low to sustain substantial injection. For now, the second recommendation is being followed. PG&E predicts a continual decline in productivity until offset by natural recharge such as heavy rain, flood, seepage, and deep percolation or sources of water for injection can be found. Some possibilities of sources of injection fluid are being investigated, including treated sewage effluent. In December 1991, the TAC proposed five key elements on the plan to maximize generation through efficient and economic utilization of the remaining reserves at The Geysers [1]. The five elements were: (a) power plant improvement or shutdown and steam shifting between plants, (b) water injection, (c) variable generation or load following, (d) additional drilling, and (e) steam quality improvement between reservoir and turbine. After examining the plan, the committee found that the options identified are reasonable for further study and evaluation. The committee was not, however, convinced that all elements of the plan will further the objective of reducing the rate of steam decline. As an example, further drilling was not considered to be a steam decline mitigation measure and could in fact aggravate the reservoir decline situation.

2.2.2 Variation in Fuel or Resource Quality

A geothermal reservoir is not homogeneous. The reservoir is fault-controlled which means that the resource is extracted by drilling into a fault structure. This also means that any deviation from these structures can adversely affect the temperature and quantity of steam produced from a given production well. Many of the wells drilled in The Geysers have not been economical producers and have been abandoned. Also, the quality of the resource can vary from site to site, particularly with regard to the levels of H_2S in the steam. This will affect the amount of abatement required and, therefore, the operational costs. Because of the concerns in the declining steam production in The Geysers, no new installed capacity should be anticipated in the near term.

2.2.3 Lack of Suitable Sites [2]

Due to the mountainous terrain of The Geysers area and the need to site power plants relatively close to steam'resources, there is a growing shortage of suitable sites for large central plants. Preferred sites have historically been on ridgetops where solid bedrock can provide a strong foundation. Ridgetops, however, can pose visual, erosion, and sedimentation problems. As development moves to less preferred sites, the costs to mitigate these problems will increase. Additional suitable sites exist for smaller modular plants. As the required space decreases, the availability of sites increases and costs of required mitigation measures decrease.

2.2.4 Availability of Transmission Lines [2]

Currently, there are transmission systems rated at 60, 115, and 230 kV in The Geysers, with the bulk of the power being transmitted west and south on PG&E's 230 kV system through Castle Rock Junction to either Fulton or Lakeville. This system has a design capacity of transmitting electricity from approximately 2,200 MW of installed capacity. Potentially, this system could transmit up to 2,800 MWs but increasing transmission losses after 2,200 MW make this load uneconomic.

Installed capacity at The Geysers is approximately 2,000 MW, creating a need for either an additional transmission line or redesign of the existing system to eliminate its redundancy. A 230 kV transmission line called the Geothermal Public Power Line has been proposed to be constructed east from The Geysers. If approved and completed, this line would add approximately 800 MW of transmission capacity.

2.2.5 Availability of Water

Surface and groundwater is very limited in Lake and Sonoma Counties. Geothermal developers must compete not only with commercial and agricultural interests but, in the case of Lake County, with neighboring jurisdictions which have rights to surface and groundwater.

Current power plant design uses condensed steam as cooling water. Most of the resource that is produced is lost through evaporation and only 15 to 20 percent is injected back into the aquifer. This has resulted in reservoir pressure drops at some

sites. Attempts to extend the life of the steam field by injecting surface and/or ground water could increase the demand for water which may not be available from existing sources.

At The Geysers in California, production declines could be substantially improved by injection of water from external source. However, there is a shortage of water for recharging the hydrothermal reservoir, due to multiyear drought. Competition with rural farmers and urban residences for water has led to shut-in capacity rather than a recharging of the aquifer. Use of treated sewage effluent could supply needed recharge if this were economically feasible[1].

2.3 Economic Barriers

The sunk costs for the geothermal resource development and the time delays in negotiating a contract within the utility company placed a heavy financial burden on the geothermal steam supplier. In addition, the economics of geothermal power plants are dependent on: cost of fuel, expected future cost of fuel, length of term loans available, interest rates, insurance of risks, and possibility to obtain fixed rates for long periods (equivalent to the terms of power purchase contracts)[7].

3.0 LIQUID-DOMINATED RESOURCES

There are several areas within California where liquid-dominated resources above 220°F (104.4°C) are being developed. These include Imperial Valley, Coso Hot Springs, Mono-Long Valley, and Wendel-Amadee. Other areas that exhibit temperatures above this minimum and where exploration has begun include Glass Mountain and Lassen. Since the temperature and quality of these resources vary significantly from site to site, different types of generating systems are needed, depending on the specific circumstances.

3.1 FLASHED STEAM

In a flashed-steam systems, the geothermal hot water, typically between 220°F and 350°F (104.4°C and 176.7°C), is brought to the surface and piped to a separation tank where the pressure is reduced causing the fluid to flash into steam. In a single-flash system, fluid is allowed to boil at the surface in one-stage production separation while in dual-flash system, the geothermal fluid is flashed twice, increasing the amount of steam to the turbine. Double-flash technology imposes a second-stage separator onto a single-flash system. Double-flash technology is in the range of 10 to 20 percent more efficient than single-flash technology.

Another design, called vacuum flash cycle is now being used in Japan [6]. What is different from the conventional flash cycle is that geothermal hot water from a production well is flashed in vacuum. Consequently, the whole steam system is subject to a pressure below atmospheric pressure and waste hot water from a separator is pumped out. Since steam pressure is vacuum and no steam ejector can be used, condensible gas is extracted by a vacuum pump from a condenser.

The only source of atmospheric emissions is drift associated with the cooling towers. There are minor emissions associated with well development and replacement wells.

Flashed-steam systems are being developed at several resource areas in California. The constraints associated with the technology are similar to those identified for the dry steam system in The Geysers.

3.1.1 Environmental Barriers [2]

3.1.1.1 Air Pollution

Like vapor-dominated systems, flashed-steam plants use evaporative cooling. The sources, types, and effects of emissions from flashed-steam plants and the abatement technology are nearly identical to those for dry-steam plants.

However, hydrogen sulfide (H_2S) concentrations in liquid-dominated geothermal reservoirs appear to be lower than those found in The Geysers. It is unlikely, therefore, that H_2S impacts or abatement costs will significantly constrain electrical development in these resource areas. In fact, the plants at Coso Hot Springs are being designed to abate 100 percent of H_2S emissions.

3.1.1.2 Water Pollution

The design for power plants at the various reservoirs will need to address the potential conflicts between water availability and emissions. Depending on the quality of cooling water used, other emissions problems may be encountered. The agricultural waste water used in plants in the Imperial Valley, contains herbicides, pesticides, fertilizers, salts, and other agricultural chemicals. These chemicals are likely to be contained in cooling tower emissions and deposited on surrounding land. Whether or not cooling tower drift could be a serious problem is not known at this time.

3.1.1.3 Waste Disposal

In the Imperial Valley where a majority of flashed-steam plants in California have been built, the problems associated with waste disposal can be reduced by recovering various minerals from the spent geothermal brine before the fluid is injected into the ground. Studies by Unocal have shown such recovery to be economical and that it greatly reduces the proportion of material which must be disposed of as hazardous waste.

3.1.1.4 Noise Pollution:

The issue on noise pollution is discussed in the vapor-dominated section.

3.1.1.5 Destruction/Disturbance of Habitat:

The issue on the effect of geothermal development on habitat is described in the vapor-dominated section.

3.1.3 Technical Barriers

3.1.3.1 Variation in Fuel or Resource Quality

The characteristics of high-temperature resources vary

significantly between resource areas. Generally, these resources are under high pressure and may contain high concentrations of dissolved solids. For example, the Imperial Valley, located approximately 100 miles east of San Diego, overlays one of the largest high-temperature, hot water reservoir systems in the world. Reservoir temperatures as hot as 500°F have been encountered. However, the resource quality is quite low, as dissolved solids range from 30,000 ppm to over 300,000 ppm.

Resource production and power generation equipment exposed to such chemically-reactive hot water can be severely eroded, corroded, or fouled with scale. High temperatures and pressures, in conjunction with high salinity, can accelerate the breakdown of seals, lubricants, and insulating materials. Furthermore, developing reliable technology to cope with the erosion, corrosion, and scaling caused by the hot, chemically-active fluids in the Imperial Valley has been a major impediment and a major cost factor in both fuel cycle and power plant economics. The technology, however, to separate untrained water appears to have been successfully developed for high-salinity fluids.

The Imperial Valley contrasts with other high-temperature resource areas in California. The saturated steam resource of the Coso Hot Springs KGRA exhibits temperatures exceeding 400°F (752°C), but is considerably cleaner than the Imperial Valley.

Depth to resource also varies significantly between resource areas. For example, many of the wells drilled in the Imperial Valley range from 5,000 to 9,000 feet. The resource at Coso Hot Springs is being produced from depths of approximately 4,000 feet.

3.1.3.2 Adverse Subsidence Impacts

Subsidence of the ground surface has been observed at several areas where extraction of geothermal fluids has caused the subsurface reservoir to contract. The resource area most sensitive to subsidence is the Imperial Valley where the extensive irrigation and wastewater drainage agricultural development could be adversely affected by subsidence. Imperial County has a policy requiring 100 percent injection of the fluids withdrawn from a geothermal reservoir, but has permitted most power plants with an injection requirement of 80 percent or more. To detect induced subsidence, Imperial County requires that resource developers install and survey bench marks at their wells and operate a regional first order survey network. Subsidence control will not constrain deployment of flashed-steam plants unless Imperial County requires 100 percent injection. This requirement may be imposed when the county determines that particularly sensitive facilities are located in an area of subsidence and that damaging amounts of subsidence can be reasonably predicted. In such areas, appropriate conditions, such as monitoring of subsurface compaction and compensation for damages, could also be included in the steam field and/or power plant permits.

3.1.3.3 Availability of Transmission Lines

Geothermal power plant development in the Imperial Valley and Nevada has been constrained for several years by the unavailability of transmission lines or adequate carrying capacity. This same constraint could develop in other resource areas.

3.1.3.4 Availability of Water

Surface and ground water is limited in the Coso Hot Springs. Flashed-steam plants with evaporative cooling systems will adversely affect water supplies. In the Imperial Valley, flashed-steam plants use agricultural drain water for cooling and do not face the same constraint. Although the quantity of agricultural drain water is being reduced in the Imperial Valley due to conservation measures, other sources of drain water should be sufficient for geothermal development [2]. Most plants can be designed to conserve cooling makeup by using steam condensate, and if the residual geothermal liquid is fresh enough, it can be used as well, which is not a major problem.

3.1.3 Economic Barriers

The special materials and fluid treatment required to handle the very saline resource in the Imperial Valley, as well as the relatively deeper resource, has contributed to the cost of electrical power production.

3.2 BINARY CYCLE GEOTHERMAL

Binary cycle technology incorporates two distinct closed fluid loops to generate electricity. The first loop passes hot water from the reservoir to a heat exchanger. A second loop moves a cold liquid phase working organic fluid with low boiling point (e.g., freon, isobutane, pentane or some other hydrocarbon matched to the reservoir temperature) to the heat exchanger.

The geothermal hot water or brine (typically between 300°F to 360°F (148.9°C to 182.2°C)) passes through a heat exchanger, where the heat of the fluid vaporizes the working fluid. The vaporized organic fluid is piped to the turbine-generator to generate power, condensed, and returned to the heat exchanger. The organic fluid is condensed either by evaporative cooling (as is typically done in dry-steam and flashed-steam geothermal power plants) or by air cooling.

Binary cycles have some operational and environmental benefits resulting from the fact that the geothermal fluid is pressurized. First, no gases or other pollutants contained in the geothermal fluid are released to the atmosphere. Second, binary cycle systems are relatively insensitive to the presence of noncondensible gases and to scaling problems, which can adversely affect the cost and reliability of flashed-steam plants. After passing through the heat exchanger, the cooled geothermal fluid is usually injected back into the reservoir.

The primary constraint to the deployment of any geothermal power plant technology is the requirement that the power plant be located in close proximity to a suitable reservoir. Binary-cycle power plants are least constrained because they are being developed to use moderate temperature and relatively widely distributed resources. The low efficiency requires that large quantities of cooling water be used, unless air cooling is used.

3.2.1 Environmental Constraints [2]

3.2.1.1 Air Pollution:

Binary-cycle power plants tend to have low environmental impacts because the geothermal fluid, which can contain toxic metals and gases, is not vented to the atmosphere, except during well drilling. Pollutants can be released to the atmosphere from leaks in the working fluid loop of the power plant and from wet cooling towers if agricultural waste water containing herbicides, pesticides and fertilizers is used for cooling water.

3.2.1.2 Thermal Discharge

Because of their **low** thermodynamic efficiency, binary-cycle power plants release more waste heat to the environment than other thermal power plants.

3.2.2 Economic barriers

Large power plants may be difficult to finance because of uncertainties about geothermal fluid availability over the useful life of the power plant. Financing should be less **of** a constraint to modular power plant development because the power plants can be brought on line quickly and moved to other sites if the resource fails.

3.2.3 Technical Barriers

3.2.3.1 Availability of Resource

Geoscience techniques to guide well field management procedures and to predict resource useful life are not adequately developed.

3.2.3.2 Variation in Resource Quality

Geothermal fluid geochemical, thermal, and pressure characteristics vary within and among reservoirs and over time. Power plants must be built and operated to accommodate these variations.

3.2.3.3 Utility Integration Constraints

Geothermal power plants and their associated well fields operate best and are most economic when operated in a baseload mode rather than in a dispatchable mode. Development could be constrained unless California Energy Commission's need tests for capacity additions favor geothermal energy because of its indigenous resource value, fuel diversity advantage, and low environmental impact.

3.2.3.4 Lack of Suitable Sites

Geothermal power plants can be sited only where the resource exists and other factors don't constrain siting.

3.2.3.5 Availability of Transmission Lines

Geothermal power plant development in the Imperial Valley and Nevada was constrained for several years by the unavailability of transmission lines or adequate carrying capacity. This same constraint could develop in other resource areas.

3.2.3.6 Availability of Water

Some geothermal power plants use large quantities of cooling water. For example, a 50-megawatt water-cooled binary plant requires more than 5 million gallons of cooling water per day (100,000 gallons per megawatt per day). This is significant since many geothermal resources are located in arid regions where water is scarce and regulated commodity. Thus, long-term access to sufficient quantities of cooling water could be an important constraint in the planning phase of development at some locations. However, plants can use dry cooling systems at a small increase in capital cost and some net output loss during summer. If other aspects of project economics are good, these plants can be used even where water is not available [5].

4.0 REFERENCES

1. U.S. Department of Energy, (1991). Geothermal Energy in Western United States and Hawaii: Resources and Projected Electricity Generation Supplies, Energy Information and Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, **U.S.** DOE, Washington, DC 20585.
2. Energy Technology Status Report, (1992). California Energy Commission.
3. Sam L. Altshuler and Ted D. Arcado, (1989). Ambient Air Monitoring at The Geysers: A Historical Perspective and Current Status. ***Geothermal Resources Council, Transactions,*** Vol. 13, 71-74.
4. Bing Tso, Jr. (1990). Hazardous Waste Volume Reduction: A Sulfur Sludge Dewatering Facility at The Geysers", ***Geothermal Resources Council, Transactions,*** Vol. 14(2), 1169-1174.
5. R. James Brown and William P. Jordan, (1989). Element Content of Rainbow Trout and Sacramento Sucker in Streams of The Geysres Region, CA. ***Geothermal Resources Council, Transactions,*** Vol. 13, 83-90.
6. Yutaka Hibara, Takeshi Kondo, and Tetsuya Susuki, (1990). Vacuum Flash Cycle Geothermal Power Generation for Low Temperature Resource. ***Geothermal Resources Council Transactions,*** Vol. 14(2), 1025-1028.
7. Bronicki, L. Y. and Doron B. (1990). The Development of Geothermal Energy Constraints and Opportunities. ***Geothermal Resources Council Transactions,*** Vol. 14(1), 483-486.

DISCLAIMER

This paper was prepared as an account of work sponsored by the State of California. Neither the State of California nor the California Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal responsibility for the accuracy, completeness or usefulness of any information, product or process disclosed, or represents that its use would not infringe privately-owned rights.