Developing the First Commercial Geothermal Project in the Hawaiian Islands

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Introduction

The Puna Geothermal Venture (PGV) Project is a 25 MW (net) power plant and associated geothermal wellfield currently under construction for the Puna District of the Island of Hawaii. The project, located in the Kapoho section of the Kilauea Lower East Rift Geothermal Resources Subzone, will sell the generated electricity to the Hawaii Electric Light Company (HELCO) for use on the Island of Hawaii.

The PGV project is consistent with the state's objectives of providing environmentally desirable energy self-sufficiency and diversifying Hawaii's economic base. The Project is developing a new alternate energy source as well as providing additional information about the nature of the geothermal resources in the state.

PGV was formed in 1981 as a joint venture of Thermal Power Company, Dillingham Geothermal, Inc. and Puna Sugar Company, Ltd. During the first half of 1988, Ormat Energy Systems, Inc. (now named OESI Power Corporation) purchased 100 percent of the interests in PGV.

As of this date, PGV is a partnership between Constellation Energy, Inc. (CEI) and OESI. The partnership, with OESI as managing partner, has elected to perform the full spectrum of activities for the project including, financing, field development and well drilling, engineering, construction and operations and maintenance.

PGV will be the first commercially operated geothermal power plant in the state of Hawaii. The project is located approximately 21 miles southeast of the city of Hilo in the Puna District on the Island of Hawaii in the immediate vicinity of the 3 MW state-owned HGP-A research and geothermal demonstration facility. The project will occupy some 25 acres of surface area within a dedicated 500-acre project area in the Kapoho section of the Kilauea Lower East Rift Geothermal Resource Subzone. The Kilauea Lower East Rift subzone was established in 1984 (Act 151) under Chapter 205, Hawaii Revised Statutes, which mandates the designation of geothermal resource subzones for geothermal exploration and development. PGV presently has a total of 10,361 acres under lease for geothermal development. Nearly all of PGV's acreage is leased from three major landowners. The remaining acreage is leased from 17 private landowners.

Geologic Setting

The PGV site straddles the axis of the Lower East Rift Zone (LERZ) of the Kilauea Volcano. The LERZ extends eastward over a distance of 34 miles on the Island and continues an additional 20-30 miles eastward on the subsea flank of the Island. The LERZ has been volcanically active for several thousand years and currently represents the primary avenue of magma drainage from the magma chamber beneath the Kilauea Caldera. Eruptions have occurred along its entire length over the last 36 years. The current eruption flowing from fissures in the vicinity of Pu'u O'o started in 1983 and has been flowing continuously since that time. The discharge rate has been stable at about 500,000 to 600,000 cubic meters per day. The current eruptive center is located about 23 km west of the PGV site. The most recent eruption to take place at the PGV site was in 1955.

The LERZ is characterized by pervasive fractures and vent lineaments that are aligned parallel to the axis of the rift. Along the central axis of the rift, the land surface is subsiding at a rate of approximately 1 inch per year. Tensional tectonics are evident throughout the project site where numerous open fractures are found at the surface. These fractures are typically one to three feet in width and are vertical or very steeply dipping. Many of the fractures discharge warm, moist air which emanates from the warm water table at a depth of 600 feet below the surface.

The high temperature geothermal reservoir within the project area begins at a depth of approximately 4,000 feet below ground surface. The reservoir rock consists of a basalt dike complex of nearly vertical dike swarms separated by septa of brecciated wall rock. The dikes are typically one to three feet thick. The reservoir temperature ranges from 620 to 660°F.

The relatively low reservoir permeability is controlled primarily by pervasive micro-fracturing. The fractures are nearly completely filled with minerals including chlorite, quartz, anhydrite, and pyrite. Fracture filling may be the primary cause for the relatively low productivities of 70 to 100 kph observed in the PGV production wells. The thickness of the reservoir is not known but drilling results from PGV production well KS-3 indicates that it extends to a depth of at least 7,400 feet.

The reservoir is overlain by approximately 3,000 feet of submarine basalt flows with very low permeability. The thermal gradient in this zone averages 20°F/100 feet but in some intervals exceeds 50°F/100 feet. The upper 2,000 feet of rock overlying the reservoir consists of subareal basalt flows which are highly permeable and contain an active unconfined aquifer. The aquifer is fed by heavy rainfall of 120 to 200 inches per year which falls throughout the region. Within the project area, natural leakage from the geothermal reservoir produces anomalous groundwater temperatures ranging from 98 to 130°F and salinities ranging from 1,000 to 5,000 ppm.

Project Description

The PGV project will generate up to 28.5 MW of electrical power so that 25 MW can be delivered to the HELCO electric grid system, with the balance of the power being consumed by the plant equipment. The actual amount of power generated will vary in response to steam quantities, atmospheric temperatures and other operating conditions.

The power plant consists of the following major systems:

- Ten nominal 3 MW modular turbine-generating units. Each module will contain the following turbine-generating equipment:
  - *a nominal 1.8 MW backpressure steam turbine;*
  - *a nominal 1.2 MW binary cycle turbine which generates additional electricity from the low-pressure steam leaving the backpressure turbines;*
  - *a 3 MW double-ended shaft generator commonly driven by both turbines; and*
  - *air-cooled condensers for the working fluid in the binary cycle; and*
  - *power and control cabinets.*
- Injection system for the produced geothermal fluids including noncondensable gas compressors and mixing elements.
- Steam production system including steam separators and brine surge tank.
- A rock muffler, holding pond and H_2S abatement system for emergency use.
- Central Station Control.
- Two 69 kV transmission lines, each 18.5 miles long, and interconnection facilities including switchyard and substations.
- Office, warehouse, work shop and control building.
- Auxiliary facilities such as air compressors, fire protection equipment and emergency diesel generation.
- Wellfield consisting of up to 14 production and injection wells located at five different wellpads.

Power Production

Geothermal fluid from all wells will flow through a flash separator that will partition the geothermal brine from the geothermal steam and noncondensable gases. At least two wellfield gathering systems will be used to move the geothermal brine and geothermal steam to the power plant. A third pipeline may be needed to collect geothermal steam condensate produced by heat losses in the steam gathering lines. These pipelines will gather the appropriate fluid(s) and gases from each wellpad and will be routed to the power plant site together and, where practical, adjacent to the wellpad access roads. The steam will be delivered to the power plant system; the brine will be delivered to the brine surge tank for injection.

Figure 1 shows a simple schematic diagram of the PGV project steam turbine/binary cycle power plant system. The proposed 1.8 MW modular backpressure steam turbines exhaust a significant amount of heat energy which is converted into electricity by the binary power generating units known as Ormat Energy Converter (OEC) units.

The backpressure steam turbine/binary cycle power plant is a closed system that, during normal operation, does not release any hydrogen sulfide (H_2S) or other gases to the atmosphere. A small fraction of the noncondensable gases will remain in the geothermal brine during the initial separation process. However, most of the noncondensable gases will be partitioned with the steam during the initial separation process, pass through the steam turbine, and be routed along with the low pressure steam to the heat exchangers in the OEC units. There the working fluid will condense the steam while extracting the latent heat for electrical production. The condensate will then be mixed with the brine for injection. The remaining gases, still under low pressure, will exit the OEC units and be compressed and injected into the mixture of condensate and brine, and the recombined stream injected into the geothermal reservoir.

The noncondensable gases produced from the Puna geothermal reservoir will be dissolved and entrained in the produced geothermal fluids by in-line mixing, and all of the produced fluids and gases will be injected into the geothermal reservoir. To ensure the reliability of the injection system, a spare pump, a spare compressor, and a spare injection well is provided. A holding pond is provided to collect liquids in

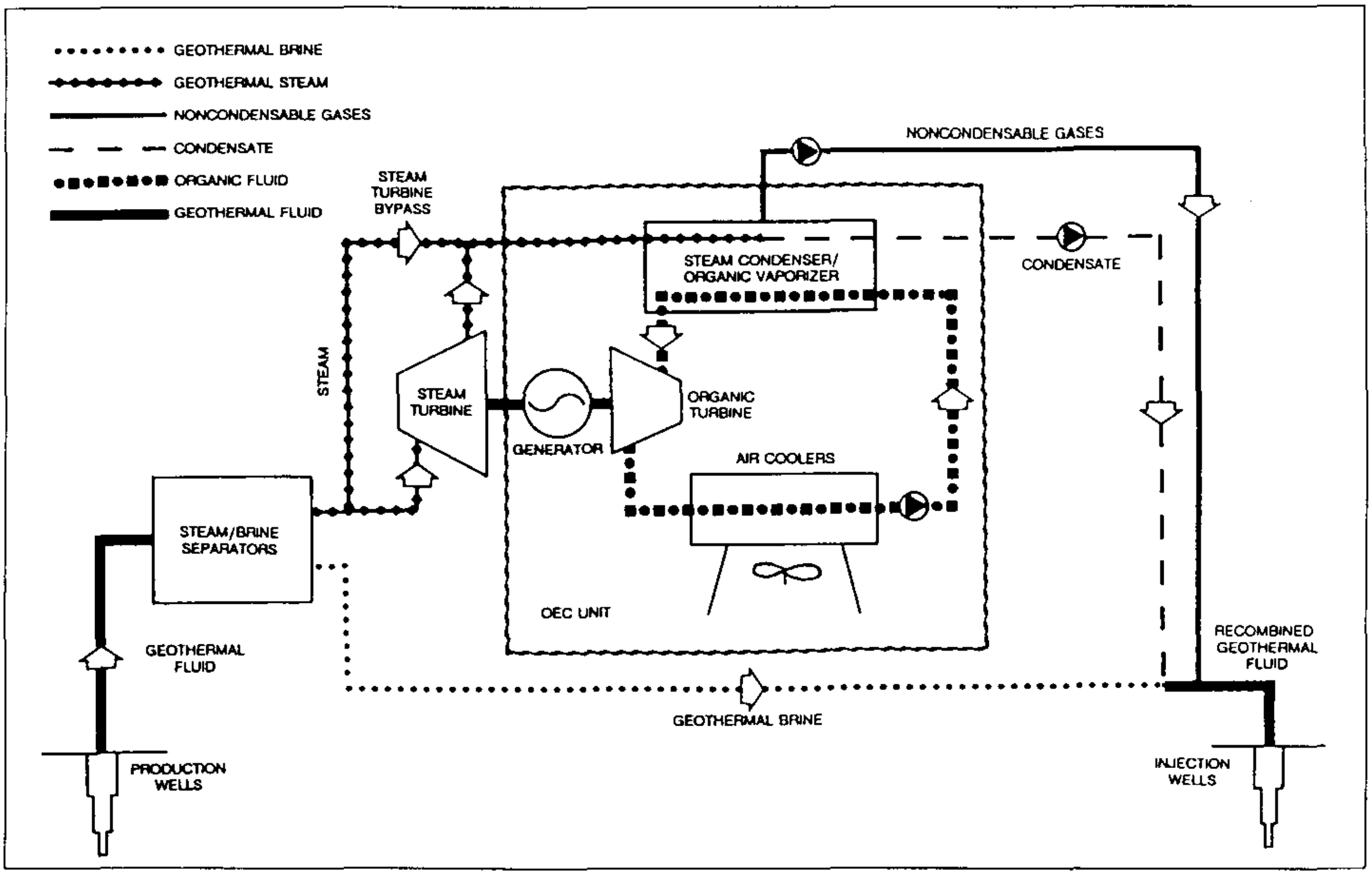


Figure 1. Puna Geothermal Venture schematic diagram.

the event of an upset in the liquid injection system.

A steam turbine bypass system is installed on each steam turbine unit so that its OEC unit can operate even when the steam turbine portion is not in operation (such as during plant start-up). In this situation, the geothermal steam bypasses the steam turbine and enters directly into the OEC vaporizer, where it condenses as in during normal operation conditions.

When the entire power plant is shut down, an emergency steam release facility will be used to release steam, treated with sodium hydroxide (NaOH) to remove 96 percent of the H_2S through a rock muffler (which will reduce noise levels) while the wellfield production rate is reduced to 30 percent of full flow.

Engineering/Construction

The project was taken from a conceptual engineered design to the detailed design during an approximate 1-1/2 year period prior to the start of construction. This development phase of the engineering directly involved OESI personnel and direct subcontracts to various engineering firms. The civil and electrical detailed design was performed by local Hawaii firms with HELCO, the purchasing utility, performing the transmission and interconnect design. The detailed mechanical engineering design, as well as the original conceptual design, was performed by OESI and its affiliates.

Project construction commenced following a local "site blessing" on 11 September 1990. The total power plant construction has been awarded to union subcontractors. The trade unions, to their credit, exhibited their support throughout the project permitting process and have continued this support through the construction phases.

The project facility has the following major areas of work:

- The power plant, being the largest single area of work, has utilized several areas of construction and engineering discipline. The Ormat Energy Converters (OECs) encompass the most substantial segment of the Facility. The 10 units are divided into five north and five south units. Site work commenced on the south site in September and is now complete. Construction of the South OEC area has been the center of work concentration as this area will be utilized for the initial power output targeted for the Second Quarter of 1991, with the north OEC area being completed in parallel to the time the south OEC units coming on-line. This, in itself, exemplifies a major positive side of the facility's modular construction and design. The power plant has several ancillary areas that are being constructed in parallel with the south OEC area, as they are required for operation of the facility. These areas are the 13.8 kV distribution system, the noncondensable gas compression and condensate injection system, the steam release system, the binary storage area, the raw water and fire protection system, the 480 V emergency power system, the instrument air system and the power plant control system. All of these ancillary systems are well underway, nearing completion or awaiting system testing and shakedown in early June 1991.

- The project will transmit 13.8 kV power to its substation via underground cable where it is transformed into a voltage compatible with the HELCO grid system. The substation includes two 32 MVA transformers (one dual voltage), two circuit switchers, and the transformer and line protection relays and equipment. The construction of the substation began in November 1990 and is now complete and awaiting relay testing and plant output. This facility is adjacent to the utility (HELCO) switchyard.

- The HELCO switchyard was constructed by the project as part of the Plant Interconnection Agreement and consists of a "breaker and a half" scheme utilizing four circuit breakers, relays, SCADA equipment for the operation and interconnection of two 69 kV transmission lines. The switchyard is under construction with an anticipated completion date of mid-May 1991. A contract was executed with HELCO to design and construct two 69 kV transmission lines of approximately 18.5 miles in length each.

- Transmission line construction began in December 1990 with the 34.5 kV system being energized in February 1991. The first of two 69 kV lines is expected to be complete by September 1991, with the second 69 kV line being completed in September 1992. Each 69 kV line is capable of handling the plant capacity. The two lines provide redundancy to maintain project availability for baseload conditions.

The field development construction is divided into several areas:

1. The gathering system is the piping system that interconnects the anticipated eight production wells and two injection wells to the facility. This gathering system begins at the wellhead of the production wells and carries two-phase brine/steam to the main separation area. Construction of the main separation area began in December 1990 and is now complete, awaiting hydrotesting and commissioning. The separated outflow of steam is transmitted to the power plant via a dedicated pipeway. Construction of this pipeway also began in December 1990 and is nearing total completion with one of two main steam headers 100 percent installed and the brine pipeline underway. It is anticipated that the one line system will be completed and tested by late May 1991 and the second line completed by August 1991.

   The field gathering system to each wellpad is based upon well and pad completion and, as of this writing, one of two geothermal lines has been constructed to Wellpad E and the interconnection work to Well KS-3 is underway. The interconnection of Well KS-3 to the main separation area will be complete by mid-May 1991.

2. The injection gathering system is awaiting the completion of Well KS-8, which is now underway. This well, when completed, will be interconnected to the power plant NCG/condensate system. Because of its close proximity to the plant, the injection piping will be completed within two weeks after the completion of Well KS-8.

The completion of the remainder of the geothermal gathering system is based upon well completion and will consist primarily of mechanical piping installation. All pipeway foundations are already completed. The completion of this work is anticipated to be early Fourth Quarter 1991 and is expected to support the 25 MW output by late November 1991.

Construction Considerations

All construction areas mentioned herein share some common logistical problems which require continuous attention and involvement of the project management staff:

1. Shipment to the island by boat/barge proved time consuming and required significant expediting functions in order to meet delivery milestones;
2. The climate in the area of the project produces high rainfall on an annual basis and this past year set a rainfall record in the neighboring Hilo area (217 inches). The rainfall has obvious direct impacts on trade work such as welding, concrete finishing, painting, electric terminations, and any other process requiring "dry" conditions to effectively perform the work. The indirect or unmeasurable impact by the rainfall is on the productivity and morale of the work force. If a facility identical to PGV was constructed in a dryer climate, it is believed a comparison would indicate a vast improvement in onsite manpower output;
3. The project site chosen was located uprift on the lava flow of 1955. This site is composed predominantly of fractured basalts laced with small lava tubes and stress fractures. While the site poses no potential long-term problems to the project, a substantial amount of rock excavation, lava tube grouting and soil import was required for the site grading. Trenching for cabling/piping was accomplished with hydra-hammers or blasting, and in the field development, well cellar and drilling reserve pits were loosened by blasting. In short, this type of civil work is more expensive and takes signifi-

cantly longer than in areas of soft rock or soil.

4. Shortage of qualified labor. The project labor force peaked at approximately 150 construction personnel. The subcontractors have encountered difficulty in locating enough skilled craft personnel. While PGV is by no means a large project by mainland comparison, it is large in relation to the regular activities of the local unions and has produced a shortage of skilled craftspeople such as carpenters, ironworkers, welders, pipefitters and high voltage electricians.
5. Permitting Requirements. The project permitting produced several developmental requirements that have necessitated strict construction controls. The project has a 7:00 a.m. to 7:00 p.m. work rule which includes large vehicle deliveries on highways adjacent to the project. Since the project is being constructed near local housing, a sound limitation was implemented of 55 db at the nearest residence during daylight hours and 45-50 db (depending on wellpad utilization) during nighttime drilling operations. On occasion the project has elected to suspend certain drilling operations at night and have scaled down equipment utilization during daytime operations in order to maintain compliance with the imposed limitations. The project has never been cited due to sound and emission issues.

Drilling and Testing

The wellfield will consist of eight production wells and two injection wells. The wells are drilled directionally from five wellpads as shown in Figure 2. The number, location, and surface area of the pads are limited by permit conditions. The directional program is designed to allow coverage of the entire resource area from the allotted wellpads. A typical directional program consists of kicking off at a depth of 2,150 feet and building 3°/100' to 13°. This angle is then held to total depth at 7,400 feet, resulting in a total horizontal offset of approximately 1,200 feet.

Production wells are cased to a depth of 4,000 feet and completed with a 7 inch slotted liner hung through the production interval. The casing points are selected to prevent cool water entry into the wellbore and insure that the shallow groundwater aquifer is not contaminated in case of leakage in the upper 2,000 feet of the casing string. The casing design for a typical production well is shown in Figure 3.

The wells are drilled in 45 to 60 days and cost approximately $2 million each. Drilling in the upper 1,000 feet is typically done without mud returns due to the extreme permeability of the basalt flows. Aerated water and foam are used in this section. The remainder of the hole is drilled with mud. Air drilling through the production zone is not possible due to the sloughing formation and permit restrictions relating to noise and H_2S emissions. Drilling into production zones is usually signalled by partial loss of circulation.

The casing is subject to significant thermal stresses both under static and producing conditions. After completion of each well, the lower part of the casing string is heated to temperatures in excess of 500°F while the upper 2,000 feet casing remains at a temperature of 100 to 130°F. The slotted liner is subject to temperatures ranging from 620-660°F. During production, the temperature in the lower part of the well drops by approximately 200°F while the upper part of the well heats up more than 300°F. Premium grade casing and careful attention to cementing procedures are required to prevent casing failures under these conditions.

The well test for KS-3 was performed after allowing the well to heat up for approximately 60 days after completion. Wellhead pressure at the end of the heat-up period was approximately 50 psi. Well flow was initiated by first bleeding the well for one hour at a rate of 50 gpm. During this time, the wellhead pressure rose to approximately 850 psi. The well was then discharged vertically at full flow for approximately three hours to facilitate cleanout of the wellbore. Flow was then diverted to the test facility consisting of a separator with steam and brine metering runs. The well test lasted for seven days.

During the flow test, several temperature-pressure logs were run in the well using Kuster tools. The pressure drop in the reservoir was 2,100 psi for a corresponding mass flow rate of approximately 90 kph. This large pressure drop is indicative of the extremely low permeability of the reservoir. The steam fraction was approximately 70 to 80 percent of the mass flow at the planned power plant separation pressure of 210 psi.

The noncondensable gas content of the reservoir fluid was approximately 1,700 pm with an H_2S content of 800 ppm. During the test the H_2S was abated in the steam fraction using a 50 percent caustic solution injected at a rate of 35 gal/hr along with water injection at a rate of 70 gpm. During the seven-day flow test, no H_2S was detected beyond the project boundary down wind of the test facility. H_2S monitoring equipment used during the test by both PGV and the Hawaii Department of Health had a detection limit of 1 part per billion.

Spent geothermal brine, steam condensate, and noncondensable gases will be recombined and injected back into the reservoir. The injection wells are completed with the same cemented casing string as that used for production wells. However, instead of the slotted liner, a stainless steel hang down liner is suspended from the wellhead to a depth of 4,000 feet at the bottom of the 9-5/8 inch. This is done to protect the 9-5/8 inch casing from the corrosive injectate. The annulus between the 7 inch liner and 9-5/8 inch casing will be continually purged with deoxygenated water.

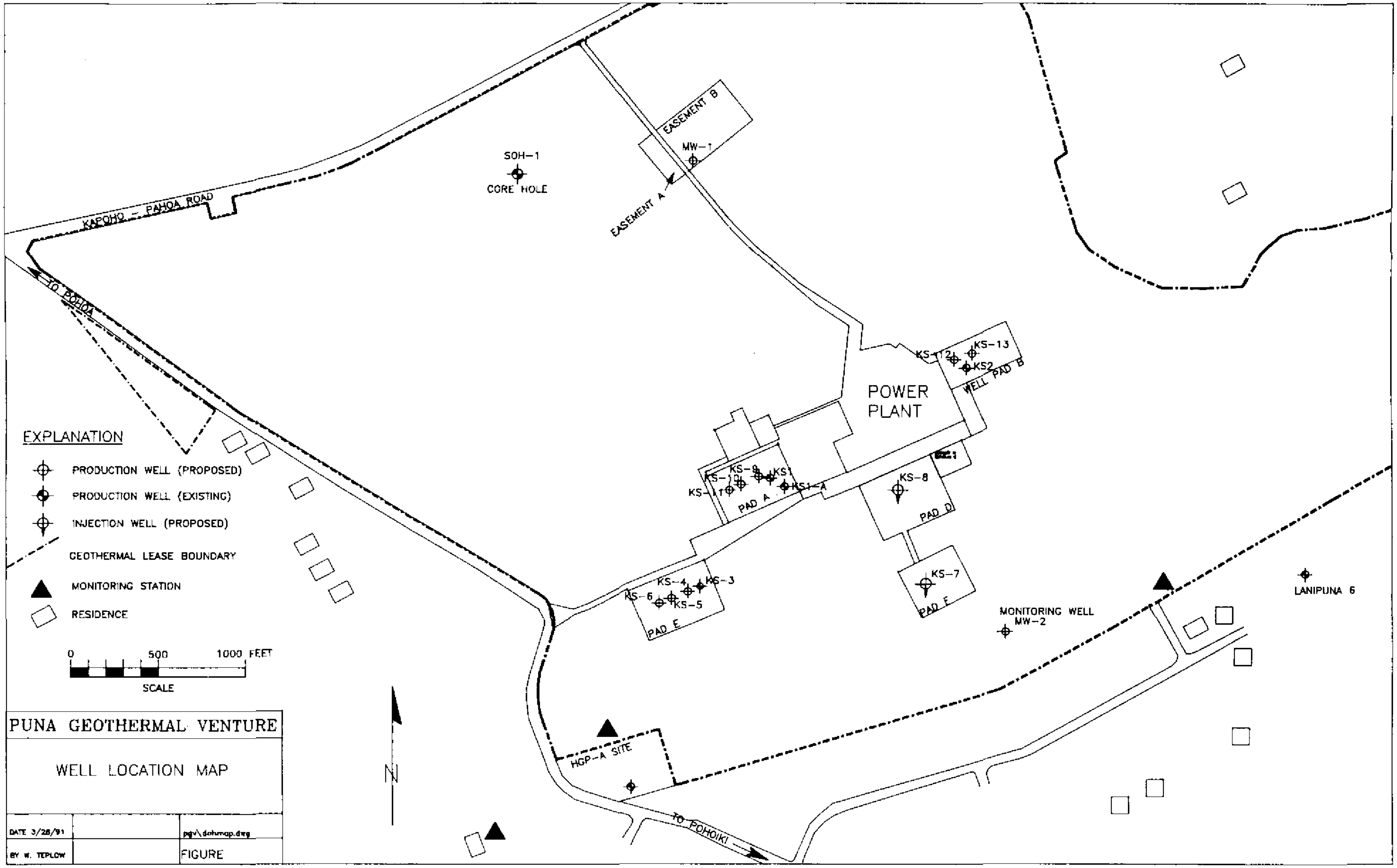


Figure 2. Well location map.

Environmental Mitigation and Monitoring

The Puna Geothermal Venture project is being constructed, and will operate, under an extensive list of conditions specified by permits issued by the state and by the County of Hawaii. The Hawaii County Planning Commission issued a Geothermal Resource Permit under the Commission's Rule 12 on October 3, 1989. The 51 special conditions attached to this Geothermal Resource Permit specify the regulatory conditions and many of the environmental mitigation and monitoring requirements for the project in the areas of noise, groundwater, air quality, public health and safety, and socioeconomics. The Hawaii State Department of Health issued separate Authority to Construct permits for the geothermal power plant and geothermal wellfield on February 9, 1990. Following modifications made to these permits on March 6, 1990, a total of 48 special conditions, dictating reporting, monitoring, and environmental mitigation requirements, were attached to these two permits. Other major permits were issued by the Hawaii State Department of Land and Natural Resources (Plan of Operations) on March 10, 1989, and by the Hawaii State Department of Health (Underground Injection Control Permit). Numerous additional minor permits have also been required and obtained. Environmental Management Associates, Inc. of Brea, California, acted as Puna Geothermal Venture's regulatory consultants throughout the permit acquisition process.

Compliance with the permit conditions has dictated the preparation, submittal, and approval of numerous secondary plans, reports, notifications and programs, including: air, groundwater and noise monitoring programs; landscaping and revegetation programs; an emergency response plan; Best Available Control Technology determinations; and site and visual plans, among others. The time required to complete, submit, and obtain ap-

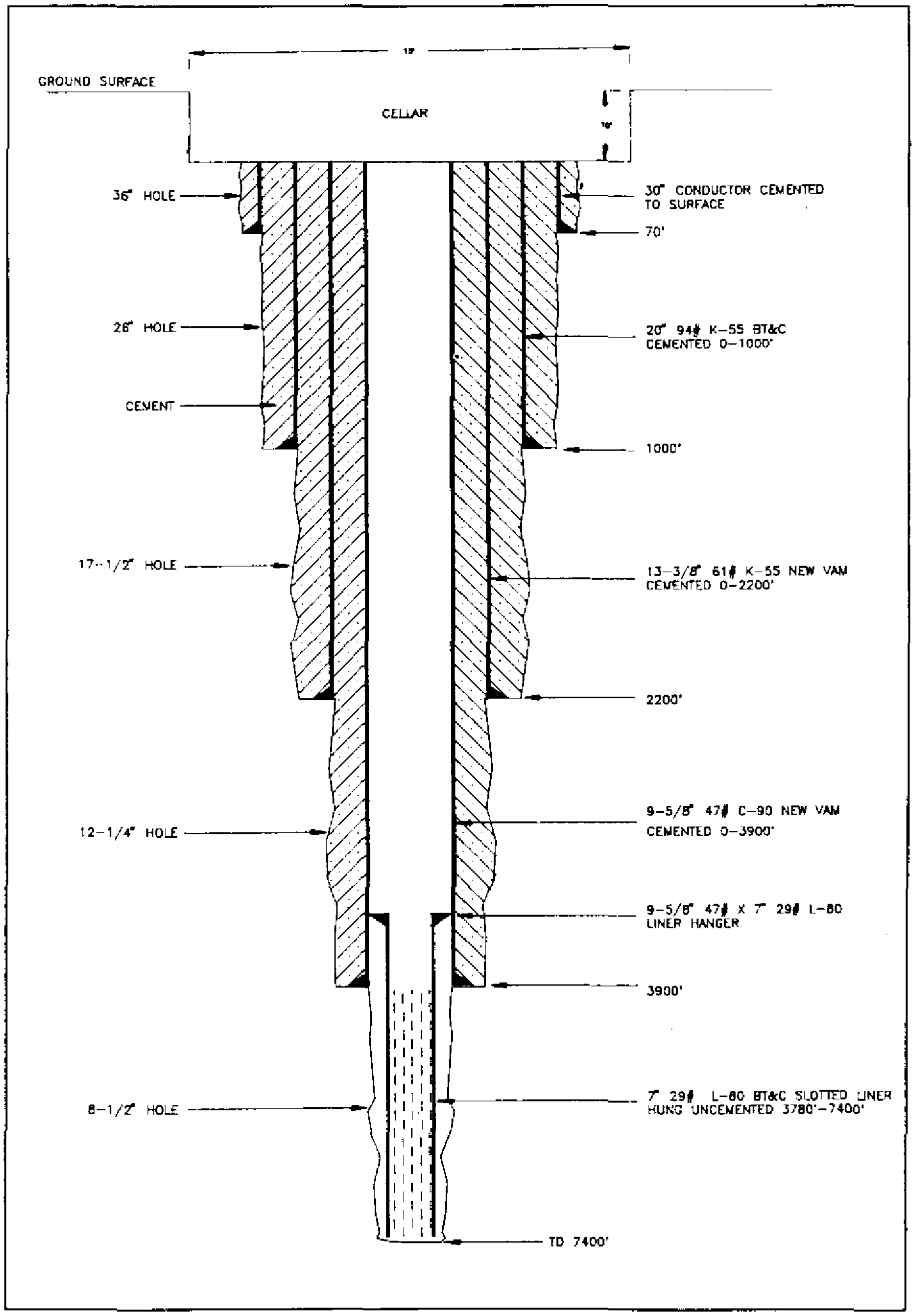
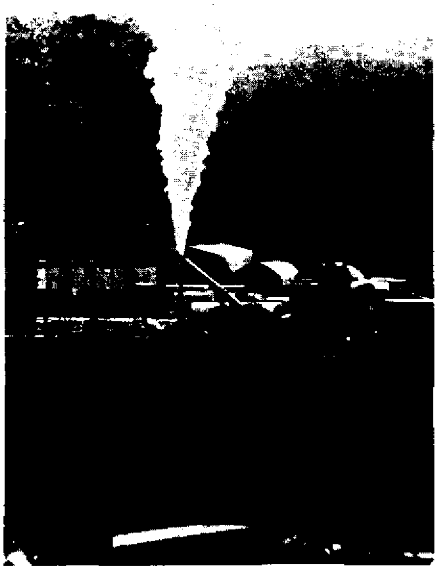


Figure 3. Production well casing design.



Venting of well KS-3, Puna District, Hawaii proval (as necessary) of these plants, notifications, reports, and programs delayed commencement of construction until the fall of 1990. However, PGV continues to comply with the complex requirements of these conditions, and the results of the required noise, groundwater, and air quality monitoring programs, currently being conducted by Science Applications International Corporation (SAIC) have demonstrated that the environmental affects of the project during the construction phase are exceedingly small.

Despite OESI's extensive experience in constructing geothermal power plants, the construction of Puna Geothermal Venture, the first commercially operated geothermal facility in Hawaii, has been a learning experience for all involved. It represents a testament to the cooperational determination, pride and skill of all parties involved. This learning experience will be utilized by OESI and other industry developers in the future for the development and construction process of environmentally safe geothermal facilities in the Islands. □

LOCATION OF THE 2nd IGA SECRETARIAT

Following the selection by the IGA Board of Directors of the U.S. proposal to host the Secretariat during its second term in the U.S., the IGA Secretariat will relocate as of 1 July 1991, to Berkeley, California, at the Lawrence Berkeley Laboratory (LBL) of the University of California. The new address, telephone, and facsimile numbers will be:

IGA SECRETARIAT
c/o Lawrence Berkeley Laboratory
Building 50C, Room 106
One Cyclotron Road
Berkeley, California
Telephone: USA 415-486-4584
Fax: USA 415-486-4889

The term of the Secretariat at LBL will be from 1 July 1991, until 30 June 1994, and the Executive Director, effective 1 July, will be Michael H. Wolfe.