HAWAII AND GEOTHERMAL WHAT HAS BEEN HAPPENING?

Compiled by
Tonya L. Boyd
Geo-Heat Center

Donald Thomas, SOEST, University of Hawaii, Hawaii
Andrea T. Gill, DBEDT Energy, Resources and Technology Division, Hawaii

INTRODUCTION

The Hawaiian Islands lie above a geological "hot spot" in the earth's mantle that has been volcanically active for the past 70 million years, with the island of Hawaii (the "Big Island") having the most recent activity. The Big Island has an obvious, large potential for geothermal energy resources, both for electrical generation and direct utilization. Since the 1976 drilling of the HGP-A well and the discovery of the Kapoho Geothermal Reservoir in the lower Kilauea East Rift Zone, geothermal power potential on the Big Island has been estimated at between 500 and 700 Megawatts (Thomas, 1987).

As a historical note, King Kalakaua, who was on the throne of the Hawaiian Kingdom before Hawaii became a state, had extraordinary vision regarding many things, including electricity. Kalakaua, along with several of his closest advisors, visited Thomas A. Edison in New York in 1881 because the King was interested in replacing the kerosene lamps being used at his Iolani Palace with electric lamps. Because of his efforts, Honolulu became one of the first cities in the West to have electric street lights when Princess Kaiulani closed the switch that provided the power, not from the volcano, but from a nearby hydroelectric plant (Energy, Resources, and Technology Division, 2002d).

GEOTHERMAL RESOURCES (Thomas, 1984 and 1985)

Geothermal interest was motivated by the fact that imported oil is used to supply over 90 percent of Hawaii's energy needs. No other state in the U.S. is so critically dependent on imported oil. Obviously, geothermal was originally regarded as a renewable source to help make the islands less dependent on imported energy.

The Hawaii Geothermal Resources Assessment Program was initiated in 1978. The preliminary phase of this effort identified 20 Potential Geothermal Resource Areas (PGRAs) using available geological, geochemical and geophysical data. Figure 1 shows a map of the major islands of Hawaii and the location of the 20 PGRAs. The second phase of the Assessment Program undertook a series of field studies, utilizing a variety of geothermal exploration techniques, in an effort to confirm the presence of thermal anomalies in the identified PGRAs and, if confirmed, also more completely characterize them. A total of 15 PGRAs on four of the five major islands in the Hawaiian chain was subject to at least a preliminary field analysis. The remaining five were not considered to have sufficient resource potential to warrant study under the personnel and budget constraints of the program.

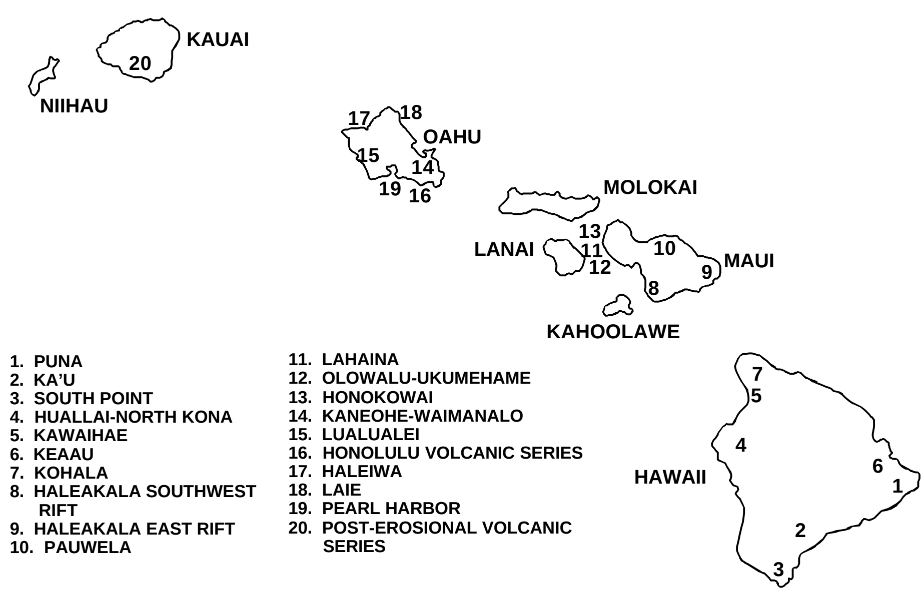

Figure 1. Map of the major islands of Hawaii showing the location of the 20 Potential Geothermal Resource Areas (PGRAs) (Thomas, 1984).

The island of Kauai is the northernmost and oldest major island of the Hawaiian chain. It is made up of a single volcanic shield that completed its most active stage of volcanism nearly 3.3 million years ago. It was not studied during this phase, due to the absence of significant geochemical or geophysical indications of a geothermal resource. The great age of volcanism on this island would further suggest that should a thermal resource be present, it would be of low temperature. The probability of a viable geothermal resource of even a moderate temperature (less than 100ºC) existing on Kauai is believed to be 5% or less. It is nonetheless noteworthy that test holes drilled for groundwater exploration in the Lihue area during the 1990's did encounter warm (~30ºC), slightly brackish groundwater.

The island of Oahu, the major population center of Hawaii including Honolulu with a total population of 876,000 and area of 1,550 km^2, is the second oldest major island and was formed from two independent volcanic systems. A preliminary assessment identified six locations where available data suggested that a thermal resource might be present. The present assessment of the geothermal potential for Lualualei Valley is that there is a 10 to 20% probability of a low-to-moderate temperature resource existing at depths of less than 3 km. The probability of the existence of a moderate-to-high temperature thermal resource within 3 km is less than 5%. The potential for geothermal in Mokapu Peninsula is less than 5% for a low-to-moderate temperature system at a depth less than 3 km. The assessment for Koolau Caldera is less than 10% for a low-to-moderate temperature geothermal system less than 3 km deep. The probability of a high temperature system at these depths is less than 5%. The potential of geothermal system within a depth of 3 km for other PGRAs located on Oahu is considered very unlikely.

The island of Molokai is the smallest of the major islands and was formed principally from two volcanoes. Due to the anticipated small demand for geothermal power on the island of Molokai in the foreseeable future, only preliminary efforts were made to assess the potential for a resource on this island.

Maui is the second largest and second youngest island and is made up of two independent volcanic systems. The preliminary assessment surveys indicated six locations that might have a potential for geothermal resources. Of the three located on West Maui only one has a potential greater than 5% for a low-to-moderate geothermal system. The Olowalu-Ukumehame Canyon was assessed at having a 60 to 70% probability of having a low-to-moderate resource and a less than 10% probability of having a moderate-to-high temperature resource. The other three PGRAs are located on Haleakala Volcano. Only two of them showed significant findings of a geothermal resource. The Northwest Rift Zone has a probability of 10 to 20% for a low-to-moderate temperature resource and less than 5% probability for a moderate-to-high temperature resource. The Southwest Riff Zone has a greater probability at 30 to 40% for a low-to moderate temperature resource and 15 to 25% for a moderate-to-high temperature resource.

The island of Hawaii, with a population of 148,700 and an area of 10,400 km^2, is the youngest and the largest island in the Hawaiian chain that is made up of at least five volcanic systems. Figure 2 shows the major rift zones and calderas of each volcano on the island of Hawaii. Seven locations were identified as PGRAs in the preliminary assessment. One PGRA, the Kilauea East Rift Zone, was later designated as a Known Geothermal Resource Area (KGRA) due to the discovery of a productive geothermal well. The probability of a geothermal resource in this area is 100%. The Kilauea area also includes the Southwest Rift Zone that has a geothermal resource probability of 100% for a low-to-moderate temperature resource and 70 to 80% for a moderate-to high temperature resource within 3 km of depth. The Mauna Loa area did not exhibit any significant indications of a geothermal resource; therefore, the probability of a geothermal resource is less than 5% for a low-temperature resource. The probability of a low-to-moderate temperature resource existing in the Kawaihae area is 35 to 45% and the probability of a moderate to high temperature resource is less than 15%. The upper flanks or summit of Hualalai indicated a probability of a low-to-moderate temperature geothermal resource at 35 to 45% and the probability of a moderate-to-high temperature resource at 20 to 30%.

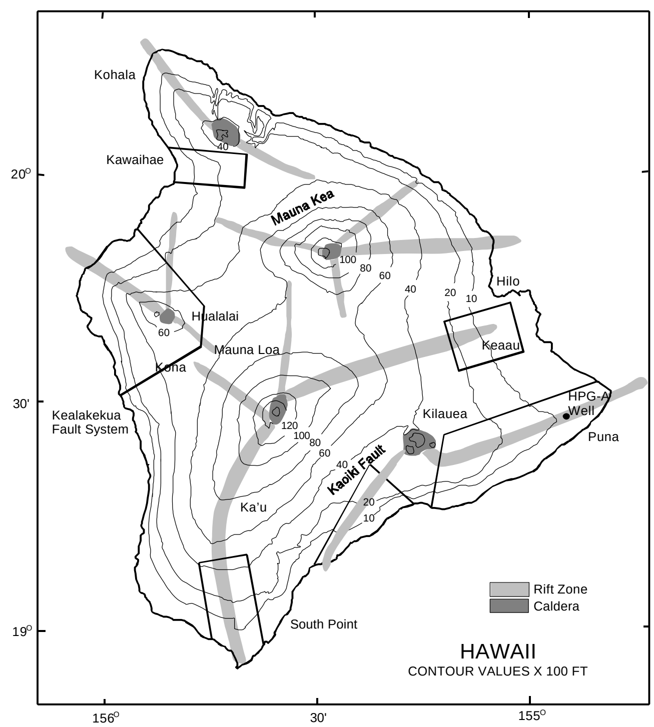

Figure 2. ***Map of the island of Hawaii showing the major rift zones and calderas of each volcano (Thomas, 1984).***

COMMUNITY GEOTHERMAL TECHNOLOGY PROGRAM (Gill-Beck, 1988 and 1990)

In 1976, a public-private partnership developed the well HGP-A in the lower Kilauea East Rift Zone on the southeast side of the island. At the time it was drilled, it was recognized as one of the hottest wells in the world. It had a bottom hole temperature of 676ºF (358ºC), a depth of 6,450 ft (1,966 m) and it produced 80,000 lb/hr (36.3 tonnes/hr) of a mixed fluid (57% liquid and 43% steam). The surface temperature during production was 365ºF (186ºC).

An experimental 3 MW power plant went online in 1982; which, when it was shut down after eight years of production, had an availability factor of 95%. The plant was originally designed as a two-year demonstration project and incorporated several unique characteristics. Because the facility was located in the Kilauea East Rift Zone and therefore, was in a high lava hazard zone, the turbine-generator set was built on skids, and the building housing the turbine-generator had a bridge crane capable of lifting the turbine-generator unit, so that it could be quickly removed in the event of a lava flow. In addition, the well was housed in a concrete bunker that could be completely enclosed with a set of covers, to allow a lava flow to cover the site without damaging the wellhead. Over the life of the plant, the generator facility produced between 15 and 19 million kilowatt-hours of electricity per year. In 1986 the HGP-A facility was transferred from USDOE (U.S. Department of Energy) ownership to the state of Hawaii and assigned to the Natural Energy Laboratory of Hawaii.

Figure 3. The HGP-A power plant showing the generator and turbine set inside the building (Lund, 1985).

In 1985, the Noi‘i O Puna (Puna Geothermal Research Center) was dedicated adjacent to the power plant. It was established to support direct use of the unutilized heat from the brines of the HGP-A well. The Community Geothermal Technology Program (CGTP) was conceived in 1986. The purpose of the program was to support small business enterprises in the Puna District, encourage the use of waste heat and byproducts from HGP-A, and to allow access to the geothermal resource.

Figure 4. Blessing of HGP-A facility by a local Hawaiian minister at the transfer ceremony. Dr. John Shupe, one of the major promoters of HGP-A is standing on the far right (Gill-Beck, 1986).

Figure 5. Governor George Ariyoshi speaking at the dedication of Noi‘i O Puna Laboratory (Gill-Beck, 1985).

There were two rounds of small grants offered, through the CGTP, to entrepreneurs in 1986 and 1988. The first round awarded grants for five projects. They were 1) Green Papaya Powder Drying, 2) Bottom Heating System using Geothermal Power for Propagation, 3) Experimental Lumber Drying Kiln, 4) Hawaii Glass Project, and 5) Cloth Dyeing by Geothermal Steam. The second round also awarded five grants which included 1) a continuation of the Bottom Heat Project, 2) Geothermal Aquaculture Project, 3) Silica Bronze, 4) Media Steam Sterilization and Drying, and 5) Electrodepostion of Minerals in Geothermal Brine. A brief summary of each project follows.

The Green Papaya Powder Drying Project looked at converting an existing fruit product processing business from electric to geothermal heat. This grant included the building and testing of a drying cabinet and production of dried fruit products such as papaya, banana and pineapple slices.

The Bottom Heating System Using Geothermal Power Project was also another proposal to convert an existing system to geothermal. This was a demonstration to see if it was feasible to heat a greenhouse using a bottom heating system which circulates hot water beneath flats of sprouting plants. The soil being warmed by the hot water facilitates the germination and growth of certain plants. Figure 6 shows Ornamental palms in the experimental greenhouse. It was founded that the rate of germination of some species improved as much as ten times during the project.

Figure 6. ***Ornamental palms in the experimental greenhouse during the Bottom Heating System Project (Camera Hawaii, Inc., 1987).***

The Experimental Lumber Drying Kiln Project proposed to design a kiln and totally automate it. There was limited commercial lumber kiln space on the island of Hawaii, so this project was proposed to reduce the need for shipping the lumber out of state for kiln drying or air drying locally which can take up to a year. Even though the heat exchanger design produced lower temperatures than the optimal temperature of 140ºF (60ºC), they were able to produce satisfactory results repeatedly after four and eight weeks of operation.

The Hawaii Glass Project was proposed to use the silica produced by HGP-A well. This was a waste product from the well that dries to a powder in the brine percolation ponds. A unique glass formula was devised using the silica and the formula was 93% of indigenous Hawaii origin. The project was not anticipated to result in a commercial glass jar or bottle making company since the amount of silica would be insufficient for a full-scale facility.

The Cloth Dyeing by Geothermal Steam Project was proposed to see if it was viable to transfer a business from Iwate Prefecture, Japan to Hawaii. The proposers found the colors were more colorful in Hawaii than in Iwate due to the chemical composition of the steam. Figure 7 shows samples of the hand-dyed silk treated with the raw geothermal steam. The dyed fabric received high grades for steadfastness and permanency. This is the only project in the first round of grants that used raw steam.

Figure 7. ***Samples of the hand-dyed silk treated with raw geothermal steam (Camera Hawaii, Inc., 1987).***

The Geothermal Aquaculture Project investigated the potential of initiating a business to sell turn-key, small-scale aquacutlure systems, as well as demonstrating the value of geothermal heated water. Tilapia was selected for the initial experiment. The tanks of simple construction used a low-input, recirculating system with a biofilter to allow a high density population. Even though Hawaii has fairly mild and uniform temperatures (20 to 30^{0}C), output can be approximately doubled using the constant temperature geothermal resource.

The Media Steam Sterilization and Drying Project proposal consisted of applying geothermal steam to shredded, local materials such as coconut husks to develop a sterile growing media. To prevent the spread of diseases carried by soil organisms, a nursery export business requires pasteurized growing media. Peat moss was the media that was imported at the time. Replacing the peat moss with an indigenous product would benefit the entire industry.

The Silica Bronze project proposed using the silica brine from the disposal ponds as a refractory material used in casting bronze artwork. The silica has been imported to Hawaii in bulk. If the silica can be recovered from the silica pond, washed and dried it may prove to be suitable for refractory use. Part of the project was concerned with developing simple ways to recover the silica from the ponds, wash it, and dry it so would be in the proper form suitable for refractory use.

The Electrodepostion of Minerals in Geothermal Brine research project was aimed at determining the nature and possible utility of minerals deposited from the hot fluid. Past research has indicated that calcium carbonate can be successfully taken from seawater. Possible future commercial applications of the deposited materials made this an intriguing bench-scale research project.

There was significant interest in the direct use of geothermal energy. Some additional proposed applications which were not funded by the CGTP include: Fruit fly disinfestation, Refrigeration, Spas, Cement Formula, Curing, Distillation, Electricity, and Polystyrene Expansion.

The HGP-A power plant was closed in late 1989 on the order of Governor John Waihee and County of Hawaii Planning Director Duane Kanuha. The closure of the power plant was permanent due to the fact that it was no longer accomplishing it's primary goal of demonstrating the benefits of geothermal power. Although the facility was designed for only a two-year demonstration life, it has been operated for nearly eight years. During the interval, inadequate maintenance had taken a severe toll on the reliability and effectiveness of the equipment, and the costs of operation exceeded the revenues being produced by the power generated. In addition, the effluent abatement systems and the brine disposal processes were neither efficient nor acceptable to the community or the regulatory agencies.

Despite the difficulties that were encountered, the facility accomplished a great deal. It demonstrated that the resource in the Kilauea Lower East Rift Zone was robust: the decline in production from the HGP-A well, over the eight year life of the plant, was only a few percent per year. The facility demonstrated that the reservoir fluids required special handling and maintenance, but also demonstrated that fluid chemistry issues could be managed. Some of the techniques for fluid handling and disposal that were developed and tested at the HGP-A facility were employed by the subsequent commercial power plant and proved key to disposal of their waste fluids. And, finally, the operations, and missteps, taken at the HGP-A facility, served to sensitize Hawaii's regulatory agencies to issues regarding geothermal development that affect the community. It should also be noted that, with the closure of the power generation activities at the HGP-A, the Community Geothermal Technology Program also was terminated due to loss of the waste heat produced by the generation process

GEOTHERMAL/INTERISLAND TRANSMISSION PROJECT (Fesmire and Richardson, 1990; Bonnet, 1990)

From 1982 through early 1990, an engineering feasibility project was undertaken to evaluate the technical and economic challenges of installing a large-scale 500-megawatt geothermal/interisland submarine cable. About $26 million (Federal and State funding) was expended in studies, design, engineering, fabrication, and testing for the Hawaii Deep Water Cable Project. Figure 8 shows the proposed route for the Hawaii Deep Water Cable. The design criteria stated that the cable(s) would have to be able to withstand the stresses of at-sea deployment (including strong currents, large waves, and strong winds), the undersea environment (including corrosion and abrasion), and be able to reliably conduct electricity for thirty years. Since the Alenuihaha Channel is nearly 2,000 meters deep, both deployment (laying of the cables) and operating environment posed unique engineering challenges.

The rationale for the project was that the primary source of geothermal energy was on the island of Hawaii, and the major electrical load was on the island of Oahu, where Honolulu is located. The scheme under consideration was to use the geothermal energy to generate power and transmit it to Oahu. At the time it was estimated that up to 500 MW could be used on Oahu, whereas only about 100 MW were needed on the Big Island.

The electricity produced by the project could potentially represent a large portion of the electric power supply for Oahu. Thus, the project would have to provide a reliable supply of electricity. The amount of energy that HECO (Hawaiian Electric Company) would purchase would be dependent on HECO's assessment of the reliability of the project and the availability of the electricity.

Two large-scale tests were conducted to examine the technical feasibility of the Hawaii Deep Water Cable. The first was the laboratory test where the cable was subjected to the electrical and mechanical loads expected during the 30 years of service. Second, the at-sea tests examined the ability of the projected, integrated control system to place the cable at the bottom accurately and to control the residual tension.

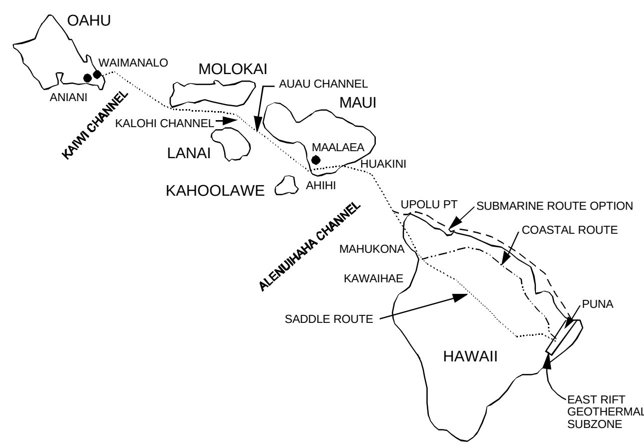

Figure 8. The Hawaii Geothermal/Interisland Submarine Cable Project Proposed Route (Fesmire and Richardson, 1990).

Over 251 different cable designs were considered. The cable tested was a double armored, paper insulated, oil filled cable designed to operate at 300 kV and transmit 250 MW of power. The cable, Pirelli Cable Design No. 116, used in the test is shown in Figure 9.

The scheme of the tests was as follows: one set of tests (the individual tests) subjected cable samples to either single worst-case loads or to loads needed to measure a characteristic of the cable; the second set (the sequence tests) subjected cable samples to a sequence of loads that duplicated the loads the cable would experience during the laying and operating for 30 years on the most hostile part of the route. Upon completion of the sequence tests, the cable sample was subjected to electrical tests. By comparing the results of this test with the results of an identical test run earlier on a new piece of cable, the effects of the sequence of mechanical loads on the electrical performance could be assessed.

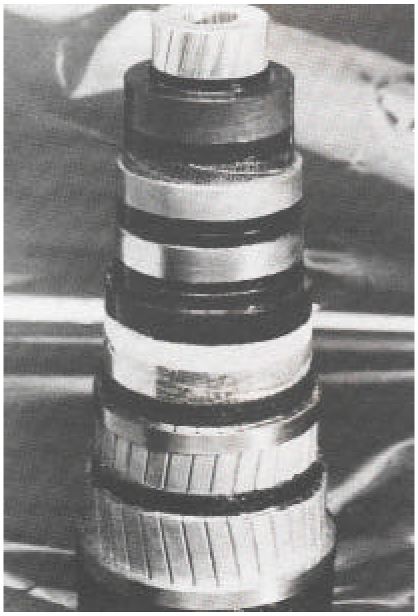

Figure 9. Pirelli Cable Design No. 116 (Bonnet, 1990).

The individual tests were:

1. Baseline electrical test,
2. High stress tensile test,
3. Static flexual rigidity test,
4. Dynamic flexual rigidity and damping coefficient,
5. Crushing test,
6. Repeated flexure test, and
7. Internal pressure test.

The sequence tests were:

1. Crushing test,
2. Bending test,
3. Cable oscillation test under simulated tidal current, and
4. Final electrical test.

The conclusions of the individual tests and the sequence tests were that the cable met the required guidelines for a 300 kV DC submarine cable. Additional tests that reflected the special conditions of the program were conducted and all tests were passed. The electrical strength of the cable and joints exceeded the acceptance requirements for use in the program. After the 30 year simulation there was no evidence of degraded performance of the cable.

A major challenge to laying the proposed underwater power cable is the formidable Alenuihaha channel between Hawaii and Maui. The Alenuihaha is renowned for its difficult currents, harsh wave conditions and strong wind velocities and is the deepest channel in the Hawaiian Islands.

A major component of the HDWC program was the at-sea test, where a test cable with similar characteristics to the proposed power cable was laid multiple times. The most difficult portions of the cable route were chosen for cable laying tests to prove the technical feasibility. The primary objects of the at-sea tests were:

- To verify the ability to accurately lay a power cable within the required path, and
- To verify the ability to control the cable tension on the ocean bottom.

A second objective was to monitor and record the performance of the laying control system, environmental conditions and the associated ship motions and dynamic tension loads in the cable for post-cruise analysis.

An 8,000-m surrogate steel cable was selected to be hydrodynamically similar to the power cable. This cable was laid and retrieved a total of three times. The first lay, under Integrated Control System control, established the success of horizontal placement accuracy with the cable being placed within 3 meters of the objective. The second and third lays were up and down the steep Kohala slope which is in the Alenuihaha channel.

The cable, while shown to be technically feasible through the research project, did not prove to be economical. Cost proposals for commercial installation of the cable demonstrated that the project could not be supported without significant government subsidies, which were not possible at the time. Currently, the state's policy supports geothermal energy production on the Big Island exclusively for use on that Island.

PUNA GEOTHERMAL VENTURE POWER PLANT (PUNA GEOTHERMAL VENTURE, 2002a)

In 1990, The Puna Geothermal Venture Facility, situated on 25 acres of a 500-acre plot, located 21 miles south of Hilo on the Big Island, replaced the HPG-A facility. This facility is in the geologic region known as the Lower East Rift Zone. Puna Geothermal Venture is the first commercial geothermal power plant in the state of Hawaii and currently is capable of producing about 30 MW of power. The power plant comprises 10 combined cycle ORMAT Energy Convertors (OECs) installed in parallel. Each OEC consists of a Level I topping steam turbine and a Level II organic turbine connected to a common generator (Ormat, undated) (Figure 10 and 11).

Puna Geothermal Venture provides nearly a quarter of the power consumed on the Island of Hawaii. That is enough electricity to meet the needs of more than 25,000 residents and visitors. As of April 2002, the power plant has produced a total of 1.9 billion kWh, and displaced a total of 552 tonnes of oil (Puna Geothermal Venture, 2002b).

In 2000, Puna Geothermal Venture announced its intention of doubling its electrical generation capacity from 30 MW to 60 MW. The expansion would be over an unspecified period of time. The wells supply geothermal steam at high pressure which must be reduced with valves before the steam goes through the generators. Puna Geothermal Venture plans to place an 8 MW generator at the well to reduce pressure to

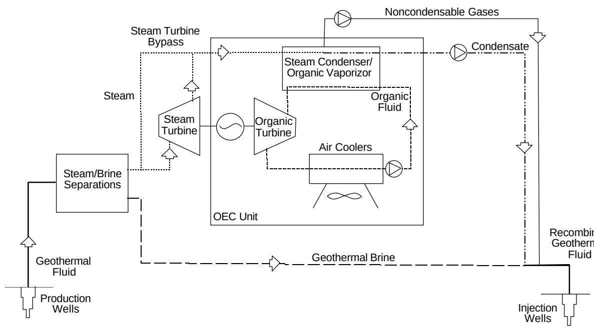

Figure 10. Schematic of the Puna Geothermal Venture Facility (Puna Geothermal Venture, 2002).

Figure 11. Puna Geothermal Venture Power Plant (Ormat, undated).

the other generators while producing power. In the long run, the company can increase capacity to 50 MW without any new wells (Thompson, 2000).

In 2001, Puna Geothermal Venture was chosen to operate the Puna Geothermal Research Center (Noi'i O Puna) facility by the Natural Energy Laboratory of Hawaii Authority (Pacific Business News, 2001). The Puna Geothermal Venture proposal consisted of continuing the existing activities and to develop new operations without doing any further drilling. They plan to solicit proposals from entrepreneurs and sell them thermal energy. PGV will refurbish and expand the visitor center and will also make reasonable efforts to solicit proposals from the public for the development, construction, operation and maintenance of a geothermal heat source on the property. If PGV receives a bona-fide proposal, they will make available, for reasonable compensation, facilities to transfer surplus heat from their neighboring geothermal facility and area within the Noi'i O Puna facility for geothermal related businesses of local entrepreneurs (Hawaii eBuzz, 2002).

BARRIERS THAT HAVE BEEN ENCOUNTERED (Lesperance, 1990 and 1991; Environment Hawaii, Inc. 1992; Energy Resources and Technology Division, 2002d)

A number of potential barriers to geothermal development in Hawaii have been overcome but some remain. A couple of the barriers, regulations and public acceptance, are discussed below.

Regulations

The regulatory regime seems to be quite complex. There is the Geothermal Resource Subzone (GRS) Assessment and Designation Law (Act 296, SLH 1983), the Hawaii County Planning Commission's Rule 12, and Act 301, SLH 1988 just to name a few.

The Geothermal Resource Subzone Law stated that the exploration and development of Hawaii's geothermal resources are of statewide benefit and this interest must be balanced with preserving Hawaii's unique social and natural environment.

Three Geothermal Resource Subzones were designated by the Board of Land and Natural Resources after evaluating a number of factors including social and environmental impacts. The subzones total 22,300 acres in the middle and lower Kilauea Rift Zone and 4,000 acres in the Haleakala Southwest Rift Zone.

Public Acceptance

The development of geothermal energy in the Kilauea East Rift Zone has stirred a significant amount of controversy. The experimental HGP-A power plant was not perceived as a "good neighbor" due to emission releases, the extent of brine ponds beyond the plant boundaries, and an unkempt appearance of the plant itself because of limited maintenance. Further exploration was opposed, often vehemently, by people expressing concern over various issues, including impacts on Hawaiian cultural and religious values, potential geologic hazards, public health, and loss of native rainforest, as well as changing the rural nature of Puna. During the establishment of the Puna Geothermal Venture plant, an episode of planned open venting and a number of uncontrolled steam releases stimulated the evacuation of some nearby residents and enhanced fears that the resource could not be safely tapped.

Since the PGV plant has been operating for a decade, most Hawaii residents have accepted it as part of the power supply. However, there is continued concern about health and environmental issues among some residents near the plant which have resulted in investigations by the US Environmental Protection Agency and a program documenting residents' health problems which they attribute to geothermal emissions. The relationship between PGV and its neighbors appears to have improved with better communication between the company and the adjacent residents.

Among the issues which have concerned geothermal opponents are:

- Interference with worship of the Goddess Pele.
- Interference with certain Native Hawaiian practices

Rainforest destruction

- Possible health and safety impacts
- Disruption of the way of life for nearby residents
- Hydrogen sulfide and other air quality issues
- Noise
- Increased strain on an inadequate infrastructure
- Impact on native fauna and flora.

In more detail some of these issues are described below.

According to state regulations, the exploration and development of geothermal resources can be permitted within conservation, agricultural, rural, and urban areas. The vast majority of resources are located in predominantly rural areas and in some cases, geothermal resources may be present in more primitive tracts where direct human impacts or occupation are minimal such as the Wao Kele O Puna rainforest. In the former case, many of the residents of these rural areas moved there to escape urbanization and industrialization of more populous countries of states (e.g., Honolulu, California), and the implementation of an industrial activity–the generation of geothermal power–was completely contrary to their lifestyle. In the latter situation, the installation of power production facilities in the rainforest–even one degraded by invasive exotic/non-native plants and animals–was equally offensive to other interest groups in the state.

An uncontrolled venting incident in June 1991 at the Puna Geothermal Venture project on the Big Island released hydrogen sulfide and other gases, and gave ample validation to the concerns of the area residents regarding the adverse impacts of this development on their communities. As a result of the "blowout," a Geothermal Management Plan was developed that has enabled state and county agencies to better regulate geothermal activity and enforce permit conditions. Nonetheless, geothermal wells are sometimes vented intentionally for a few hours to clear the well and pipelines resulting in a temporary release of steam and abated gases. These events can be noisy for a short time and, in addition, the power plant equipment (e.g., cooling tower fans, pumps, etc.) do emit continuous low-level noise during normal power plant operations. Hence, some impact on the community from power production is inescapable, and serves as a continuous irritation to those who feel that their environment has been invaded by industrialization.

A more intangible objection was also raised by some native Hawaiians who claimed that the development of geothermal power was interfering with their worship of Pele, the Goddess of volcanoes. These objections were taken as far as the U.S. Supreme Court, who found that geothermal development does not interfere with religious freedom.

The disputes over the development of a geothermal industry in Hawaii culminated in several actions by the state and the geothermal opponents that effectively ended any serious effort to develop any significant geothermal production capacity on the island of Hawaii, or in the state at all. In 1991, there were two entities actively pursuing development of the geothermal resource on the Kilauea East Rift Zone: Puna Geothermal Venture on the lower rift, and True Geothermal Energy Company in the middle rift area. The former was in the process of constructing their power plant and proving up their resource; whereas, the latter, having spent about 10 years struggling with the regulatory environment, was in the process of drilling the first of their exploration wells. When Puna Geothermal Venture lost control of one of their wells during drilling and allowed the uncontrolled release of steam from their exploration well, the state regulatory agencies suspended–indefinitely–the geothermal drilling permits of both Puna Geothermal Venture as well as the True Geothermal Energy Company. The latter company interpreted the loss of their permits–even though they were in compliance with their permit conditions–as an indication of waning political support for geothermal development by the state political powers. This loss of support, as well as less than hoped-for success in their exploratory drilling, ultimately led to their abandonment of further efforts to develop their project on the middle rift subzone.

The second event that further eroded momentum for the geothermal program resulted from an effort by the state to obtain additional federal support for the combined geothermal/inter-island cable program. In this effort, the state presented all of the state- and federally-sponsored research, development, and demonstration activities up to that date as a single unified program designed to lay the foundation for large-scale, 500-MWe-development of Hawaii's geothermal resources. Although this strategy was intended to rationalize significant, additional federal investment in the RD&D effort, it had unexpected and adverse consequences. Soon after the state presented the program as a unified effort, the Sierra Club Legal Defense Fund brought suit against the state and the U.S. Department of Energy in an effort to force the relevant agencies to conduct a Federal Environmental Impact Statement on the full 500-MWe development. The U.S. DOE expended -$5 million in an effort to conduct an EIS, but made minimal progress in meeting the demands of the geothermal opponents. Ultimately, the state and DOE settled with the plaintiffs in the suit by signing a "consent decree" that effectively barred the Hawaii governor–for the duration of his term in office–from providing support to any program that would further the state's objective of developing large-scale geothermal power production or transmission inter-island. The state's capitulation to the demands of the opponents, as well as a declining real cost of petroleum for electrical power production, effectively ended any serious effort to develop geothermal power generation beyond that of the Puna Geothermal Venture efforts on the lower east rift zone.

Nearly a decade has passed since many of these events occurred. Puna Geothermal Venture was, however, able to bring a 35-MWe power plant online–after many delays and much greater costs than had been anticipated by their original investors. Although technical challenges remain a significant concern in the operation of this facility, it has managed to produce power with a minimum of steam releases into the community and a minimum of public controversy. And the company has been able to obtain permits to expand their production to 60 MWe. However, there are no current plans to expand their production capacity, and there is little serious discussion given to significant expansion of geothermal capacity either on the island of Hawaii or elsewhere in the state. Undoubtedly, this situation is the result of the currently low cost of petroleum–in "real" dollars–but is also in recognition of the severe regulatory and political risks any new investment in significant geothermal production capacity would face in Hawaii today.

RENEWABLE PORTFOLIO STANDARD (Energy Resources and Technology Division, 2002a, 2002b and 2002c)

A Renewable Portfolio Standard (RPS) is a policy to encourage the use of renewable energy sources. It sets minimum targets for the production of electricity generated from renewable resources. The aim is to ensure deployment of renewable energy to enjoy the benefits of reduced energy costs, reduced exposure to the economic effects of volatile oil markets, risk management by diversifying generation options, job creation and economic benefits, and environmental benefits.

For a state such as Hawaii, with its extremely high dependence on imported fuels for energy (90% of the energy supplies - oil and coal - are imported), increased use of renewable energy would achieve increased energy security, reduce some of the environmental risks associated with fuel transport, and reduce the flow of money out of the state. The cost of electricity in Hawaii is the highest of any state in the United States with average price per kWh in September 2000 of $0.144 -- over twice the U.S. average price per kWh of $0.0691.

Not only were Hawaii's electricity prices per kWh the highest in the nation in October 2000, electricity revenues per kWh for Hawaii utilities grew much faster than the U.S. average over the years since 1990. Hawaii's revenues per kWh were 59.6% higher than the average for 1990 while the U.S. average was only 3.3% higher. For comparison, Honolulu consumer prices increased about 25.5% from 1990 to 1999.

Electric utilities in Hawaii are "regulated monopolies" meaning they are allowed to operate without competition, but must follow rules set by the Public Utilities Commission. By adopting a renewable portfolio standard, the use of renewable energy becomes one of those rules.

Hawaii's dependence on fossil fuels is expected to grow over the coming decade unless action is taken to increase the use of renewable energy. In 1999, Hawaii's four electric utilities sold 9,373.8 Gigawatt hours (GWh) of electricity. Statewide, utilities forecast that electricity sales will grow at an average annual rate of 1.6% during the 1999 through 2010 period, reaching approximately 11,192 GWh in 2010.

In 1999, renewable energy (geothermal, municipal solid waste, bagasse, landfill methane gas, hydro and wind) was used to produce 7.2% of the electricity generated for sale by the four electric utilities. Renewable energy generation capacity was reduced in 2000 by the closure of Lihue Plantation on Kauai and Pioneer and Paia Mills on Maui. If the remaining renewable energy resources in operation at the end of 2000 continue in operation through 2010, they will provide an estimated 642 GWh of sales during each year of the period. This will amount to approximately 6.6% of total electricity sales in 2001. As electricity demand grows, the percentage of electricity sales from renewable resources will decline to approximately 5.7% statewide by 2010.

Table 1 shows the generation in Hawaii used to produce electricity for sale to utility customers in Hawaii as of the end of 2000.

Hawaii has an abundance of renewable energy resources. Several studies have shown that at least 10.5% of Hawaii's electricity could be generated from renewable resources by 2010 with no increase in cost to Hawaii's residents.

Increased use of renewable energy sources through the implementation of a RPS can result in many benefits to Hawaii including:

- Reduced cost of fuel for electricity generation
- Reduced reliance on imported oil supplies and exposure to the volatile prices of the world oil market

Table 1. Electricity Generation for Utility Sales (End of 2000) (Energy, Resources and Technology Division, 2002a).

HECO	HELCO	KE	MECO
1161.0 MW OFS	65.0 MW OFS	10.0 MW OFS	32.4 MW OFS
129.0 MW CT	45.3 MW CT	42.9 MW CT	102.4 MW CT/DTCC
180.0 MW AFBC	42.0 MW IC Diesel	44.0 MW IC Diesel	114.9 MW IC Diesel
180.0 MW LSFD DTCC	22.0 MW Coal Steam		
	62.0 MW DTCC		
46.0 MW MSW	30.0 MW Geothermal	8.7 MW Hydro	12.0 MW Bagasse/Oil/Coal/Steam
3.2 LF Gas	15.7 Hydro	4.0 MW Bagasse	5.9 MW Hydro
	9.1 Wind		

OFS - Oil-fired Steam; CT - Combustion Turbine; AFBC - Atmospheric Fluidized Bed Coal;
LSFO - Low-sulfer Fuel Oil; DTCC - Dual-train Combined Cycle; MSW - Municipal Solid Waste
LF Gas - Landfill Methane Gas; IC Diesel - Internal Combustion Diesel

- Risk management by diversifying the portfolio of electricity generation options
- Job creation and economic benefits
- Environmental benefits.

CONCLUSIONS

There is still resistance to using geothermal energy by some members of he local population even though the above issues have been and will continue to be addressed by the government and the developers. However there are well organized groups such as the Pele Defense Fund, Rain Forest Action Network and various community organizations that will continue to express concern in various ways about the ability of the government and developers to provide socially and environmentally sound geothermal power. Further, the level of support given by the state's political establishment to expansion of geothermal capacity–there is presently only funding for one geothermal staff person at the state level–remains vanishingly small.

REFERENCES

Bonnet, W., 1990. "Hawaii Deep Water Cable Program," *Geothermal Resources Transactions*, Vo. 14, Part I, August 1990, p. 755-762.

Energy, Resources and Technology Division, 2002a. "Renewable Energy Requirements," http://www.state.hi.us/dbedt/ert/rps.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Downloaded 4/9/2002.

Energy, Resources and Technology Division, 2002b. "Renewable Portfolio Standards Report," http://www.state.hi.us/debt/ert/rps00.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Original report prepared by GDS Associates, Inc., Downloaded 6/24/02.

Energy, Resources and Technology Division, 2002c. "Renewable Energy," http://www.state.hi.us/dbedt/ert/renewable.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Downloaded 6/12/2002.

Energy, Resources and Technology Division, 2002d. "Geothermal Fact Sheet," http://www.hawaii.gov/dbedt/ert/geo-hi.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Downloaded 1/28/02.

Environment Hawai'i, 1992. "At Puna Geothermal Venture, Success is Always Just Around the Corner," *Environment Hawai'i*, Vol. 3, No. 6, December 1992, Environmental Hawai'i, Inc., http://planet-hawaii.com/environment/1292cov.htm, Downloaded 6/18/02.

Fesmire, V. and J. Richardson, Jr., 1990. "The Hawaii Geothermal/Interisland Transmission Project - A Status Report", Geothermal Resources Council Transactions, Vol. 14, Part I, August 1990, p. 763-767.

Gill-Beck, A., 1988. "Direct Heat Uses in Hawaii: The Community Geothermal Technology Program," *Geo-Heat Center Quarterly Bulletin*, Vol. 11, No. 2, Fall 1988, p. 8-12.

Gill-Beck, A., 1990. "Direct Use in Hawai'i: Perspectives and Prospects," *Geothermal Resources Council Transactions*, Vol. 14, Part I, August 1990, p. 751-754.

Hawaii eBuzz, 2002. "NELHA Accepts Proposal for Operation of the Noi'i O Puna Geothermal Research Facility," *Hawaii Ventures* - January eBUZZ News, http://www.hawaiiventures.com/news0102-1.htm, Downloaded 6/21/02.

Lesperance, G., 1990. "Issues Related to Geothermal Development," *Geothermal Resources Council Transactions*, Vol. 14, Part I, August 1990, p. 783-785.

Lesperance, G., 1991. "Public Information in Hawaii," *Geothermal Resources Council Transactions*, Vol. 15, October 1991, p. 437-442.

Ormat, Undated. Puna Geothermal Power Plant, Flyer, Ormat, Inc., Sparks Nevada.

Pacific Business News, 2001. "Puna Geothermal Wins NELHA Contract," American City Business Journals Inc., December 27, 2001. Downloaded 1/28/02

Puna Geothermal Venture, 2002a. "Puna Geothermal Venture," http://www.punageothermalventure.com/, Puna Geothermal Venture, Downloaded 6/26/02.

Puna Geothermal Venture, 2002b. "Current Facts," http://www.punageothermalventure.com/facts.htm, Puna Geothermal Venture, Downloaded 6/26/02.

Thomas, D. T., 1984. "Geothermal Resources Assessment in Hawaii, Final Report," Hawaii Institute of Geophysics, Honolulu (Technical Information Center DOE/SF/10819-TI), 114 p.

Thomas, D. T., 1985. "Characteristics of the Geothermal Resource Associated with the Volcanic Systems in Hawaii," *Geothermal Resources Transactions*, Vol. 9 – Part II, August 1985, p. 417-422.

Thomas, D. T., 1987. "A Geochemical Model of the Kilauea East Rift Zone," *U.S. Geological Survey Prof. Paper 1350*, *Volcanism in Hawaii*, Vol. 2, Chap. 56, p. 1507-1525.

Thompson, 2000. "Puna Plant to Double Geothermal Capacity," *Honolulu Star - Bulletin Hawaii News*, http://starbulletin.com/2000/07/07/news/story13.htm, Downloaded 6/21/02.