HAWAII GEOTHERMAL PROJECT
University of Hawaii
Holmes Hall 206 - 2540 Dole Street
Honolulu, Hawaii 96822

GEOTHERMAL ENERGY IN HAWAII --
PRESENT AND FUTURE

by

John W. Shupe, Director
Hawaii Geothermal Project (HGP)

and

Paul C. Yuen, Director
HGP Reservoir Engineering Program

Presented to the
Circum-Pacific Energy and
Mineral Resources Conference
in Honolulu, Hawaii
August 2, 1978

SUPPORT FOR PROJECT PROVIDED BY:

Department of Energy
Energy Research and Development Administration
National Science Foundation
State of Hawaii
County of Hawaii

GEOHERMAL ENERGY IN HAWAII -- PRESENT AND FUTURE

John W. Shupe and Paul C. Yuen

INTRODUCTION

The State of Hawaii, due to its geographic isolation and recent volcanic origin, is almost totally dependent for energy on seaborne petroleum. Hawaii has no known fossil fuel reserves; there is no coal coming into the State by rail; no natural gas by pipeline; and no regional grid to connect its electrical systems with those of other states or even with its separate islands. This lack of flexibility makes Hawaii particularly vulnerable to dislocations in the global energy market--which is a paradox, since the State has a variety and abundance of indigeneous alternate energy resources, both solar and geothermal.

THE HAWAII GEOTHERMAL PROJECT

The Hawaii Geothermal Project (HGP) was organized to focus the research capability of the University of Hawaii on the identification and utilization of geothermal energy on the Big Island of Hawaii. This island is the largest and the youngest in the island chain and is still experiencing growth from current volcanic activity so should have the greatest amount of heat at or near the earth's surface. Consequently, the Big Island was selected as the appropriate site for initial geothermal exploration, but subsequent surveys are to proceed throughout the State.

The initial goals and objectives of the HGP included:

1. Improvement of geophysical survey techniques for locating underground heat resources.
2. Development of mathematical and physical models to assist in better understanding of geothermal reservoir characteristics and behavior.
3. Development of efficient, environmentally clean systems for conversion of underground heat resources to useful energy.

4. Completion of socioeconomic and legal studies to assist in land use regulations and resource utilization.
5. Establishment of environmental base lines with which to monitor subsequent geothermal development.
6. Identification of potential geothermal resources, initially on the Big Island, but ultimately for the entire island chain.

A long-range objective of the HGP is to develop techniques, materials, and components for the recovery of useful energy from magma. The nature and the relative stability of the basaltic lava on the Big Island make this an ideal location for the study of power generation from magma.

The HGP came into being when the 1972 Hawaii State Legislature allocated \$200,000 for geothermal research, contingent on the University obtaining matching federal funds. This was well before the Middle East oil embargo and resulting energy crisis; so was a progressive step for a state legislature to take. From the beginning this has been a cooperative project involving all segments of government, the University, the electric utility, and the private sector. A budget summary of the total support of \$9,655,000 that has been received to date, showing sources of funding for each of the four major phases of the project, is listed on the next page.

PHASE I

Research got underway in the early summer of 1973, with separate programs established for Geophysics, Engineering and Environmental-Socioeconomics. The major emphasis of Phase I was on geophysical surveys--infra-red, gravity, electrical, seismic, geochemical, hydrological--but support activity was begun in the other programs as well. It became evident in early 1974 that an exploratory

BUDGET SUMMARY FOR HGP-A

Phase I -- Exploratory Surveys
& Related Research (May 1973
through April 1975)

Figures in \$1000

State of Hawaii	FY 72	100	
County of Hawaii	FY 72	100	
National Science Foundation	FY 73-74	469	
ERDA	FY 75	119	
Other Public & Private Funds	FY 72-75	<u>39</u>	
	Subtotal		\$ 827

Phase II -- Experimental Drilling, Initial Well Testing,
& Related Research (May 1975 through June 1976)

ERDA	FY 75-76	1,472	
State of Hawaii	FY 74	500	
Water Resources International	FY 76	60	
Hawaiian Electric Company	FY 75	<u>45</u>	
	Subtotal		\$2,077

Phase III -- Well Testing & Analysis
(July 1976 through June 1978)

ERDA	Transition Period	147	
ERDA - DOE	FY 77	270	
State of Hawaii	FY 77	<u>66</u>	
	Subtotal		483

Phase IV -- Installation of Wellhead Generator
& Assessment of Kapoho Reservoir
(July 1978 through Dec. 1980--Initial Funding)

DOE	FY 78-80	5,743	
State of Hawaii	FY 78	400	
County of Hawaii	FY 78	100	
Helco	FY 78	<u>25</u>	
	Subtotal		<u>6,268</u>

Total Funding to Date:		9,655
------------------------	--	-------

A Breakdown of This Funding by Category Follows:

Federal Support (NSF, ERDA, DOE)	\$8,220,000
State & County Support	1,272,000
Utility and Private Funding	<u>163,000</u>
Total	\$9,655,000

drilling program would be required to verify the subsurface conditions predicted by the surveys. Initially it was the intent to proceed with multiple drilling of both deep and shallow wells, but subsequent fiscal restraints limited the exploratory drilling "program" to one deep well.

The Site Selection Committee for this well was chaired by the late Dr. Agatin T. Abbott, after whom the well was ultimately named -- HGP-A, for Abbott. The committee considered all geophysical, geological, and geochemical evidence, including self-potential data from the U.S.G.S., and selected as the optimum site a location in the Puna District near the eastern rift of Kilauea Volcano, as shown in Figure 1. No State or County land suitable for drilling was available near the selected site, and after some negotiation with landowners in the area, permission was obtained from the Kapoho Land and Development Company to drill the well on a four-acre plot approximately three miles southeast of Pahoa, at an elevation of 600 feet above sea level.

PHASE II

Specifications for drilling were drawn up and invitations to bid were sent in early June 1975 to 28 drilling companies on the mainland, in Canada, and throughout the Pacific area. The only bid submitted was by Water Resources International, Inc., of Honolulu and, following extensive negotiations, the drilling subcontract was let in late-November 1975. A New Zealand geothermal consulting firm, KRTA, was commissioned to provide technical assistance and supervision of the drilling operation.

The drillsite was given the traditional Hawaiian dedication and blessing on November 22, 1975. On December 10, the well was spudded in and drilling commenced,

Locations of HGP-A, Volcanoes and Rift Zones on the Island of Hawaii

in accordance with the following casing program:

<u>Casing</u>	<u>Diameter, Inches</u>	<u>Depth, Feet</u>
Conductor	30	12
Surface	20	400
Anchor	13-3/8	1000
Production	9-5/8	2220
Slotted Liner	7-5/8	6450

Initially, drilling proceeded slowly. Tough, dense basaltic lava flows were encountered close to the surface before much weight could be put on the bit. Enlarging the hole to insert the casings was time consuming and costly. However, once the production casing was set at 2220 feet, subsequent drilling progressed rapidly for the remainder of the well. The bottom 4200 feet was drilled in less than three weeks, with a total of five days of that time devoted to logging and coring; so an average drilling rate of 270 feet per day was achieved over the lower two-thirds of the hole.

The well was completed to a depth of 6450 feet on April 27, 1976. Cores of the subsurface strata were taken at approximately 700-foot intervals and cutting samples were obtained every five to ten feet throughout drilling. The well was logged twice with Gearhart-Owen equipment, which measured resistivity, self-potential, natural gamma ray and slow neutron count, and cement bond. Depth of logging was limited by high downhole temperatures.

Below 4000 feet the drilling mud began to heat up rapidly, and subsequent mud temperature measurements approached 600°F. This high temperature was sufficiently encouraging to justify installing a slotted liner, flushing out the mud, and

conducting a well testing program. The total budget for site preparation, drilling, casing, and preliminary rig-assisted well testing came to just over \$1.5 million, as summarized on the following page.

PHASE III

Preliminary well testing proceeded through the summer of 1976. HGP-A was first flashed to produce steam and permitted to flow briefly on July 2. A four-hour flow test was conducted on July 22, verifying that natural flow of geothermal fluid into the wellbore was taking place. The quality of the fluid was generally good. It was surprisingly low in chloride content, but with a high level of silica-- which is consistent with a downhole temperature in excess of 600°F. Figure 2 shows the variation of temperature with depth immediately following the four-hour flow test, and six weeks later when the wellbore temperature had stabilized. The maximum downhole temperature of 676°F makes HGP-A one of the hottest geothermal wells in the world.

During flow, the sound of the steam discharging from the 8-inch diameter pipe at supersonic velocity was measured at 120 DBA--roughly equivalent to the noise of a 747 jet aircraft at takeoff. In order to proceed with the testing program, a silencer/separator was installed. Due to the high quality of the steam, the original silencer was only partially successful. Additional muffling and stiffening were added, after which a series of throttled flow tests was conducted to provide better assessment of the well's potential output and to obtain preliminary generator design data.

Instrumentation and procedure were developed for obtaining downhole temperature and pressure profiles during flow. Figure 3 shows a typical temperature profile

HGP-A

COST OF SITE PREPARATION, DRILLING,
AND RIG ASSISTED WELL TESTING

Site Preparation, Water Reservoir, and Cellar	\$ 45,496
Mobilization	120,192
Labor and Rig Time	733,830
Consumable Materials and Misc. Services	673,995
Electric Logging	16,486
Demobilization	<u>9,615</u>
SUBTOTAL	\$ 1,599,614
Less Credit for Returned Consumables	<u>96,143</u>
NET COST OF HGP-A	\$ 1,503,471
Less Rig Rental Time Donated by WRI	<u>60,000</u>
TOTAL COST OF HGP-A TO THE PROJECT	\$ 1,443,471

Temperature vs Depth for HGP-A

Temperature Recovery After Flow Test

78-8496M/16-19

while the well was discharging, as well as the temperature distribution two weeks after shut-in, when the wellbore approached static equilibrium.

The results of the preliminary tests were sufficiently encouraging that a planned 90-day flow test was initiated in late March 1977. However, complaints resulting from the nuisance effect of hydrogen sulphide emissions led to the termination of the test after six weeks. The decision to end the test was reinforced by the fact that the pressure-time curve for the well appeared to have stabilized.

Some preliminary results for the well are presented in tabular form on the following page. Table I lists the rates of discharge 25 hours after the well was first flashed for four consecutive flow tests. Each succeeding flow test resulted in greater steam output, suggesting either or both of the following factors: 1) There is skin damage due to partial blocking of the pores by drilling mud, and each discharge cycle unclogs additional circulation passages; or 2) Flowing the well causes temperature changes in the rock structure, which could lead to microfracturing and improved circulation.

Table II shows the effect of throttling down the flow rate by inserting progressively smaller orifices into the steam line. The maximum potential power of 3.5 MWe occurs with a three or four-inch orifice. Although the steam flow rate is somewhat less than for the full eight-inch pipe, the increased wellhead temperature and pressure raise the potential power output.

The long-range power projection for HGP-A is given in Table III and shows there is very little decline in power output over a thirty-year projected life of the well. This preliminary estimate is based upon one 1000-hour flow test and a number of pressure build up measurements.

TABLE I. DISCHARGE RATES AFTER FLOW TESTS

	<u>NOV.</u>	<u>DEC.</u>	<u>JAN.</u>	<u>MAR.</u>
Mass Flow Rate (KLB/HR)	88	103	114	120
Steam Flow Rate (KLB/HR)	60	64	72	75
Steam Quality (Percent)	68	62	63	62
Electric Power Potential, MWe	3.4	3.8	4.3	4.5

TABLE II. THROTTLED FLOW DATA

Orifice Diameter Inches	Steam Flow in KLB/HR	Wellhead Pressure PSIG	Wellhead Temp. °F	Potential Power MWe
8	64	51	295	3.3
6	65	54	300	3.4
4	57	100	338	3.5
3	54	165	372	3.5
2-1/2	48	237	401	3.3
2	43	293	419	3.1

TABLE III. LONG-RANGE POWER PROJECTIONS FOR HGP-A

Time in Years	Steam Flow in KLB/HR	Wellhead Pressure PSIG	Enthalpy in BTU/LB	Power in MWe
1	59	153	900	3.2
15	58	142	904	3.0
30	57	140	906	3.0

A summary of the preliminary test results and analyses for both the well itself, and for the reservoir associated with the well follows:

HGP-A Geothermal Well

1. Probably has severe skin damage.
2. Flashing occurs in the rock formation.
3. During flow, borehole contains steam and water at saturation.
4. Producing regions at 4300 feet and bottomhole.
5. High wellhead pressure, 160 psi @ 60 KLB/HR.
6. Potential power output, 3.5 MWe.

Kapoho Geothermal Reservoir

1. Liquid dominated.
2. Tight formation: Permeability thickness equals 1000 MD-FT.
3. Very high temperatures, (+)350°C.
4. High formation pressure, 2000 psi.
5. Slightly brackish fluid, high silica content.
6. Potentially large reservoir, 1000 MWe.

PHASE IV

The next logical step is the early installation of a wellhead generator, equipped with proper hydrogen sulfide scrubbers. This would both provide electricity for the Big Island grid and obtain additional information on the characteristics and the extent of the geothermal resource. To this end, the HGP-A Development Group (HGP-A/DG) was formed with the responsibility for constructing and operating an electrical generation plant. The HGP-A/DG consists of the State of Hawaii as the lead agency, the County of Hawaii, and the University of Hawaii. Because of legal limitations, neither the Hawaii Electric Light Company (HELCO) on the Big Island nor the parent organization, Hawaiian Electric Company (HECO), Honolulu,

are full members of the HGP-A/DG; but both utilities are active participants in the development program.

Negotiations between DOE and the HGP-A/DG were completed on May 15, 1978, for \$6,268,256 to construct a wellhead generator and support facilities. The State and County of Hawaii agreed to provide \$500,000, while the utility contributed \$25,000 and the services of a full-time engineer, in addition to agreeing to purchase up to 3.5 MWe of power. Presently, electricity from geothermal energy is first scheduled to come on line in Hawaii in July 1980.

THE FUTURE OF GEOTHERMAL ENERGY IN HAWAII

The decade of the 1980's should herald an era of extensive geothermal development in the State. HGP-A will satisfy the electrical requirements of 3500 people and provide a mechanism for assessing the characteristics and limits of the Kapoho Geothermal Reservoir. Included in this assessment will be an evaluation of the hazard of siting a power plant near an active rift zone, and procedures by which this potential hazard can be minimized.

Preliminary projections of HGP geoscientists, based primarily on estimated reservoir boundaries determined by seismic surveys, indicate that the Kapoho Reservoir may have a capacity of 1000 MWe for 50 years. One theory suggests that the entire rift zone area in Puna may prove to be an immense geothermal reservoir and, if so, could provide over 10,000 MWe for 100 years. To verify and to exploit this vast potential resource, additional wells must be drilled. Fortunately, private capital is beginning to show active interest in this development, now that the State Geothermal Regulations have been established.

There are other potential geothermal areas on the Big Island, including regions near South Point, in the Kohala Range, and at the dormant volcano, Hualalai. Geothermal reservoirs are believed to retain heat for many tens of thousands of years. Haleakala on the Island of Maui last erupted late in the 18th Century, so that Island also has geothermal potential. Both the Islands of Molokai and Oahu have warm water wells. Since the majority of the population of the State--including the City of Honolulu--is located on Oahu, the evidence of subsurface heat in Lualualei and Waimanalo is encouraging. An extensive State wide resource assessment program is underway, with major funding from DOE and some matching support by the State.

Currently the Big Island electricity demand totals only about 70 MWe, and nearly 40 percent of that is provided by bagasse (waste from sugar cane processing), which is not a likely candidate for replacement by geothermal energy. How then can the apparent surplus of geothermal power on the Big Island best be utilized? One possibility is to connect the major islands of the Hawaiian chain with an electric grid, by means of an underwater power cable. This is technically feasible, but does not yet appear to be economically sound.

Another possibility is to use the geothermal energy to process manganese modules, so abundant in the Central Pacific. Refining aluminum also is quite energy intensive and a competitive geothermal power source invites an assessment of this possibility. A number of industrial consortia are looking into both of these ore options. Should a manganese refinery be established, it could require up to 200 MWe of power; an aluminum refinery possibly twice that figure. Whether the Big Island wishes to establish an industrial park complex for this type of

economic growth is a socioeconomic issue which requires careful study.

Non-electric uses of geothermal energy also show potential: 1) Steam for sugar processing; 2) Heat for drying coffee, timber, nuts; 3) Steam for papaya and other fruit processing; 4) Heat for horticulture and mariculture; and 5) Steam for health spa and tourist attraction. Funding for the wellhead generator at HGP-A includes support for a visitor information center and provisions for using steam from the well to conduct experiments on non-electric uses of the resource, as well as to test new geothermal equipment and devices.

A long shot, if massive quantities of cost-competitive geothermal energy are found in the State, is to use the electricity to produce hydrogen by electrolysis of water. In many respects, hydrogen is an ideal combustion fuel, and also lends itself well to export.

In summary, the development of geothermal energy in Hawaii continues to enjoy the strong support of all segments of government and the scientific community. The 1978 Hawaii State Legislature passed enabling legislation to provide an additional \$1,280,000 for geothermal research, development, and demonstration on both electric and non-electric applications. As the wellhead generator at Puna begins to feed the first electricity from geothermal energy into the Big Island grid, as University scientists continue with resource assessments throughout the Island chain, and as private capital begins to accept its appropriate role both in resource development and in the establishment of energy intensive industry to utilize this resource, then we could well find Hawaii beginning to move from the economically untenable state of near-total dependence on seaborne petroleum, toward a position of energy self-sufficiency through effective utilization of its indigenous solar and geothermal resources.

ACKNOWLEDGMENTS

Those organizations which have supported this research and development program have been identified throughout the text. The authors would also like to acknowledge the following University of Hawaii colleagues who have had key roles in the Hawaii Geothermal Project, as well as others who are listed under references:

Agatin T. Abbott (deceased); Chairman, Site Selection Committee
Augustine S. Furumoto; Director, Geophysical Program
Charles E. Helsley; Geosciences Coordinator
Robert M. Kamins; Director, Environmental-Socioeconomic Program
Gordon A. Macdonald; Director, Drilling Program

REFERENCES

- A. T. Abbott, A.S. Furumoto, C. E. Helsley, R. M. Kamins, G.A. Macdonald, J. W. Shupe, P. C. Yuen; Hawaii Geothermal Project Progress Reports.
- J. W. Shupe, "Hawaii Geothermal Project Well No. 1", Proceedings of the Geothermal Conference, Palm Springs, California, April 1976.
- J. W. Shupe, R. M. Kamins, and P. C. Yuen; "Geothermal Energy in Hawaii-- Hydrothermal Systems", Proceedings of the Eleventh Intersociety Energy Conversion Conference, September 1976.
- Kingston, Reynolds, Thom, Allardice (KRTA; Auckland, New Zealand), "HGP Well Completion Report", September 1976.
- B. H. Chen, D. H. Kihara, P. C. Yuen, P. T. Takahaski, "Well Test Results from HGP-A", Proceedings of the Geothermal Resources Council Meeting; Hilo, Hawaii, July 1978.