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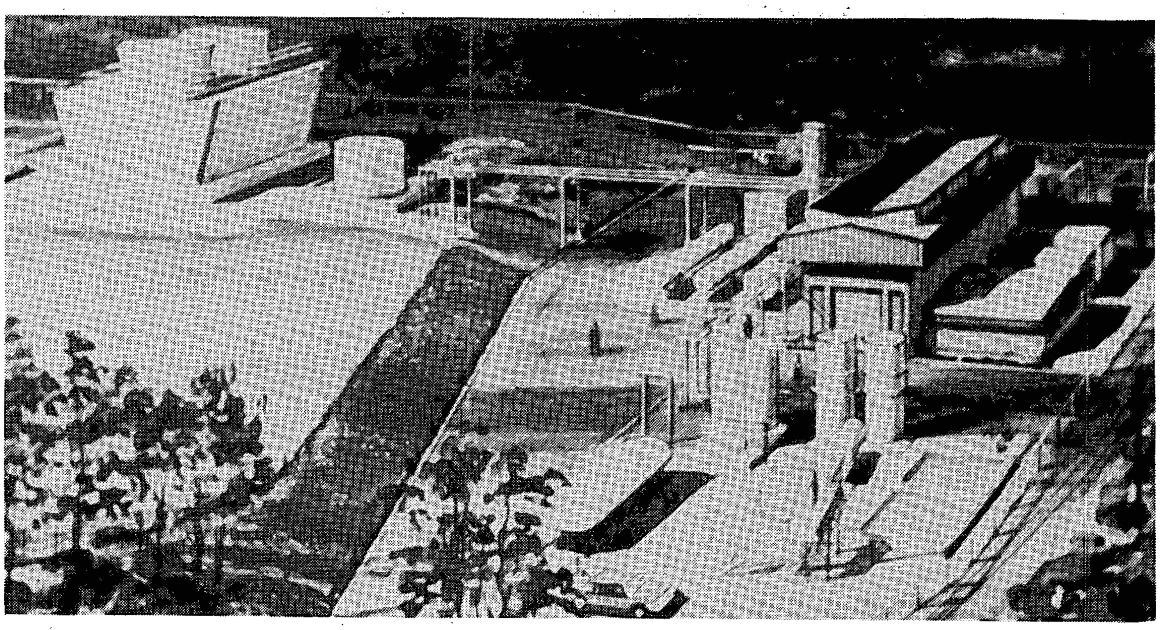

GEOTHERMAL ENERGY FOR HAWAII: A PROSPECTUS

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Prepared For: The Office of the Regional Representative, Region IX, and the Geothermal Energy Division, San Francisco Operations Office, Division of Geothermal Energy, Office of Renewable Resources, U.S. Department of Energy under contract W-7405-ENG-48

January 1981

DISCLAIMER

PREFACE

Most experts agree that development of geothermal energy in Hawaii is less a technical and economic question than a social one. In part, this is because of a geographic and cultural environment which makes the state more sensitive to technological change than the mainland United States. The impact of geothermal development will be more quickly experienced throughout the islands because of the smaller economy, the limited land area, the complex cultural setting, and the need to create new institutions with which to manage the development process.

An increasing number of developers, private citizens, engineering and planning consultants, and government officials are now becoming involved in various aspects of geothermal development. Each time a new person becomes involved, basic questions about geothermal energy and its potential uses must be answered before the person is able to make an intelligent contribution to the decision-making process. At present, such information is available only through technical reports and occasional newspaper and magazine articles.

This document is intended to provide an overview of geothermal development to potential contributors and participants in the process: developers, the financial community, consultants, government officials, and the people of Hawaii. The goal of the document is to describe the issues, programs, and initiatives that have been examined to date and, to show that geothermal energy is a realistic option in Hawaii's future.

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ACKNOWLEDGMENT

The authors would like to express their appreciation to members of the geothermal community in Hawaii for their hospitality and assistance. This document could not have been possible without the help of the staff and consultants at the Department of Planning and Economic Development, the Hawaii Institute of Geophysics, the Hawaii Natural Energy Institute, the HGP-A Wellhead Generator Demonstration Project, and members of the faculty of the University of Hawaii at both the Manoa and Hilo campuses. We would also like to thank representatives of the County of Hawaii government and the Puna Hui Ohana for their generous cooperation. And the support and guidance of the Hawaii Geothermal Advisory Committee and the U.S. Department of Energy is gratefully acknowledged.

Cover Illustration: HGP-A Wellhead Generator Project at Puna.

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1. ENERGY AND HAWAII

Hawaii is making a one-time transition from fossil to renewable energy resources. At present, the state is almost totally dependant on imports of crude oil and petroleum products and so is vulnerable to disruptions and price fluctuations in the global energy market. In 1980, annual energy imports represented an outflow of about $1 billion from the state's economy.

Because of Hawaii's recent volcanic origin and geography, the state has no indigenous fossil fuel reserves and is isolated from systems such as coal and natural gas. Fortunately, Hawaii is rich in renewable energy resources which are becoming available under new and improved technologies. These resources include geothermal, solar, wind, and ocean thermal gradients.

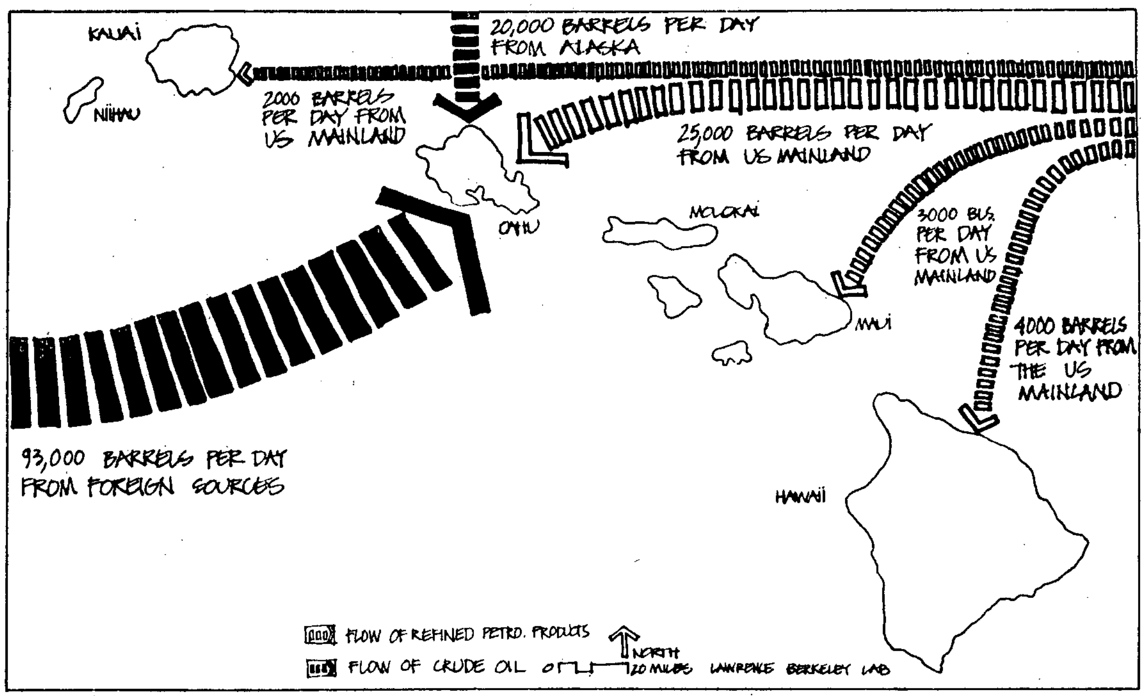


FIGURE 1: STATE OF HAWAII OIL IMPORTS

Source: Adapted from Energy Research Associates, "Study for the Development of a Petroleum Energy Data Collection and Reporting System for the State of Hawaii," prepared for the Department of Planning and Economic Development, August 1979.

Hawaii currently obtains about 92 percent of its energy supply from imported petroleum. Figure 1 depicts the flow of oil imports into the state. Crude oil is shipped to refineries on Oahu from Saudi Arabia, Oman, Indonesia, Malaysia, and Alaska. Refined petroleum products come from California, the Carribbean, and Singapore. The remainder is supplied by indigenous energy resources - bagasse from sugar mills (7%) and hydroelectricity (1%).

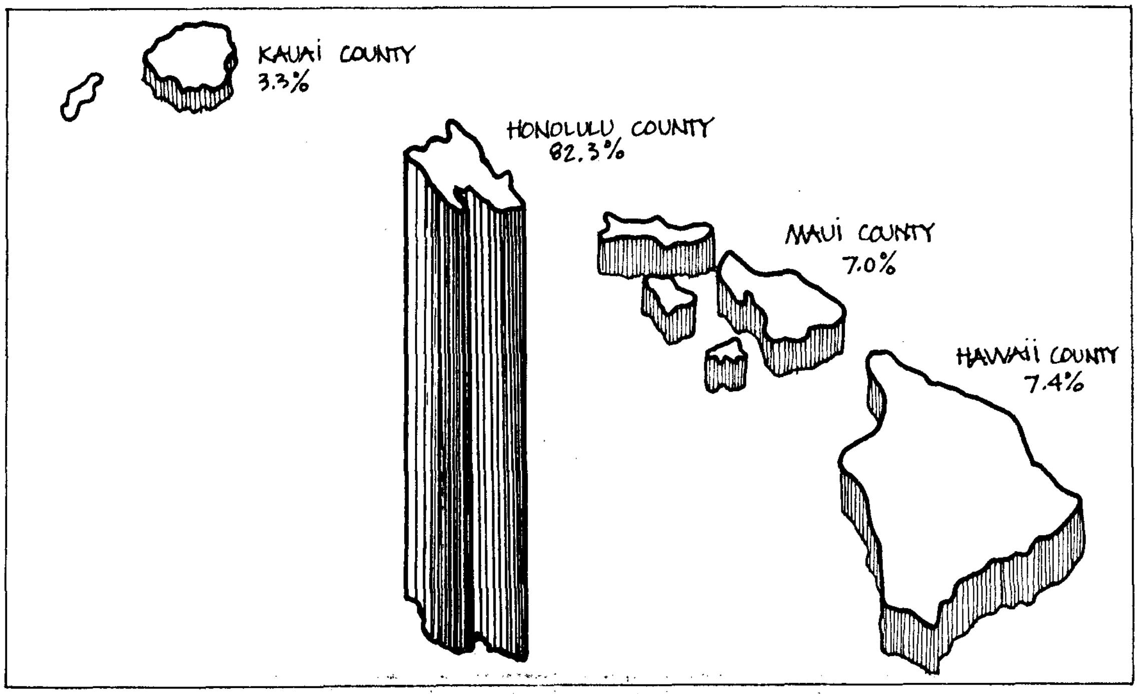


FIGURE 2: COUNTY ENERGY CONSUMPTION
Source: Adapted from Lawrence Berkeley Laboratory and Department of Planning and Economic Development, The Hawaii Integrated Energy-Assessment Project, 1980.

Energy consumption has increased from 78,940 billion Btus in 1963 to 203,940 billion Btus in 1977. Over 82% of the state's energy is consumed in the City and County of Honolulu, where the state's population and tourist activities are concentrated. Of the remainder, 7.4% is consumed in Hawaii County, 7.0% in Maui County (islands of Maui, Molokai, and Lanai), and 3.3% in Kauai County. A comparison of energy consumption in the various counties is shown in Figure 2.

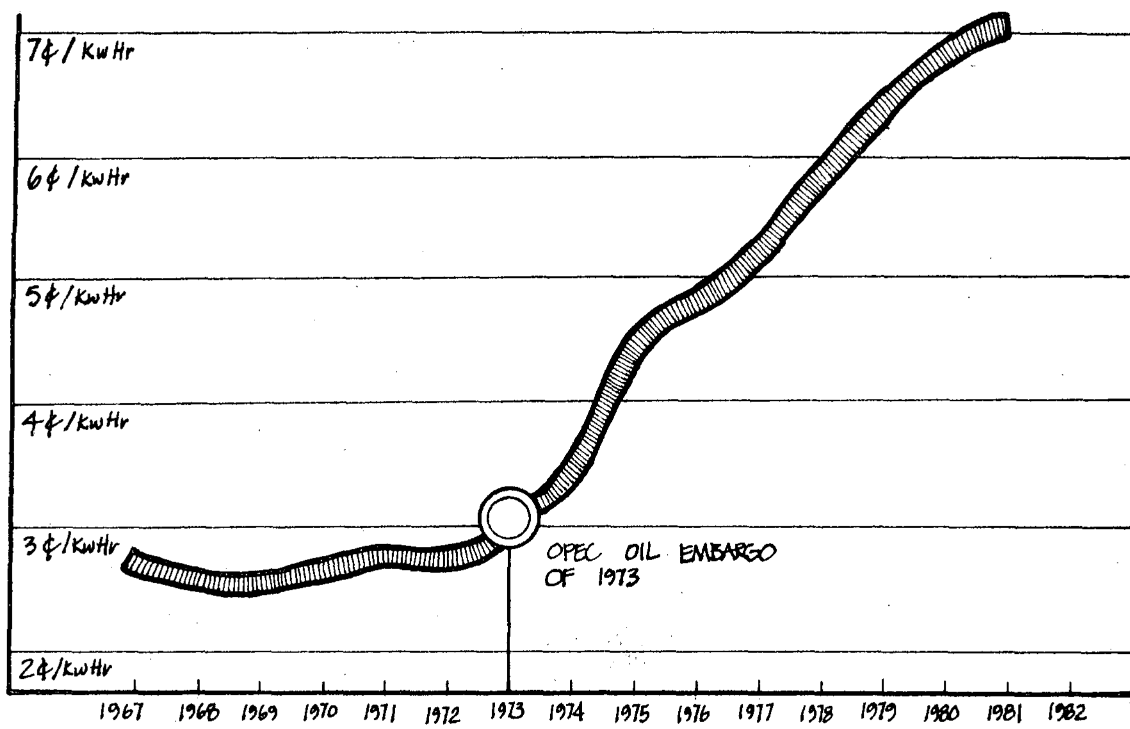


FIGURE 3: ELECTRICITY COSTS
(Average Costs per Kilowatt Hour for all Islands)
Source: Department of Planning and Economic Development, State of Hawaii Data Book, 1979.

About 20% to 25% of the State's imported fuels are used for electricity generation. Since 1974, the cost of electricity generation has trebled. See Figure 3. Many authorities believe that the price of oil (in 1980 dollars) may be $50 per barrel in 1985 and above $80 in 1990. Hawaii would have serious problems with such prices, even with a guaranteed supply of oil.

State efforts to decrease dependence on imported fuels have focused on the development of indigenous energy sources for electricity generation, and on the conservation of liquid fuels in the transportation sector. The promise of indigenous energy sources was described by University of

Hawaii researchers in a 1974 report to the Legislature. With support from the U.S. Department of Energy, the State has assumed a "Pathfinder" role in the development of alternate energy technologies. Along with the State's economic considerations for developing new energy technologies, Hawaii presents a unique opportunity to test and develop technologies of potential importance for the entire country.

A strategy for the development of renewable energy resources is described in the State Energy Plan, prepared by the Department of Planning and Economic Development (DPED). While energy self-sufficiency in the counties of Hawaii, Kauai, and Maui is considered feasible within the next decade, statewide independence is possible only if adequate energy for can be provided to Oahu from the State's energy resources.

The potential contribution of all alternate energy technologies to the State's energy self-sufficiency is being evaluated in the Hawaii Integrated Energy Assessment Project. Alternative mixes of indigenous and imported energy for the next twenty-five years are being examined to

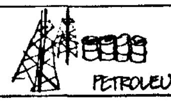
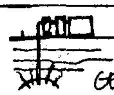
	POTENTIAL ENERGY CONTRIBUTION	ELECTRICITY SUPPLY	TECHNOLOGICAL READINESS	IMPEDIMENTS TO DEVELOPMENT
 PETROLEUM	UNCERTAIN	BASE LOAD	NOW	UNCERTAIN WORLD SUPPLIES & PRICES
 WIND	1000 MEGAWATTS	INTERMEDIATE	0–5 YEARS	STORAGE AND LINKAGE TO AN ELECTRIC GRID
 BIOMASS	1000 MEGAWATTS	BASE LOAD/ INTERMEDIATE	NOW	COST OF LAND
 GEOTHERMAL	100–1000 MEGAWATTS	BASE LOAD	NOW	RESOURCE IDENTIFICATION & CONFIRMATION
 SOLAR	2000 MEGAWATTS	INTERMEDIATE	0–5 YEARS	STORAGE AND TECHNOLOGY FOR PHOTOVOLTAIC CELLS
 OTEC	1000 MEGAWATTS	INTERMEDIATE	+10 YEARS	TECHNOLOGY RESEARCH AND DEVELOPMENT

FIGURE 4: COMPARISON OF ALTERNATE ENERGY SOURCES

Source: Lawrence Berkeley Laboratory and Department of Planning and Economic Development, The Hawaii Integrated Energy Assessment Project, 1980.

identify the constraints on and opportunities for their use. Both direct effects on the economy, including labor and materials requirements, and indirect effects on jobs and the state economy are being reviewed to define the range of conditions over which each technology would become competitive. The transition to a statewide integrated energy system would require several decades and could cost up to $10 billion.

Preliminary results indicate that over the next 25 years all renewable technologies will compete favorably with oil. A comparison of alternative energy resources is presented in Figure 4. Wind, geothermal, coal, and ocean thermal energy conversion (OTEC) systems will become feasible over the coming decade, with solar thermal and photovoltaics becoming competitive soon afterward.

2. WHAT IS GEOTHERMAL ENERGY?

Geothermal energy is heat generated by natural processes within the earth. This heat is a combination of the energy released by the decay of radioactive elements trapped within the earth and the thermal energy released when the earth was formed. Heat at the center of the earth moves toward the earth's surface by heat conduction through solid rock, and by movement of magma (molten rock) and water. If we were to drill through the crust of the earth the temperatures encountered would gradually increase at an average of about 20°C-30°C per kilometer of depth.

TYPES OF GEOTHERMAL RESOURCES

The United States Geological Survey has defined the nation's geothermal resource base as the amount of heat that might be extracted from the earth and used economically at some reasonable future time with current technological improvements. Several types of geothermal systems have been identified.

THE LEGEND OF PELE, THE GODDESS OF FIRE

"AI-LAAU, THE ONE WHO DEVOURS FORESTS AND THE EATER OF TREES, SEEMED TO BE DESTRUCTIVE AND WAS SO NAMED BY HIS PEOPLE, BUT HIS FIRES WERE A PART OF THE FORCES OF CREATION. HE BUILT UP THE ISLANDS FOR FUTURE LIFE.

THE PROCESS OF CREATION DEMANDED VOLCANIC ACTIVITY. THE FLOWING LAVA MADE LAND. THE LAVA DISINTEGRATING MADE EARTH DEPOSITS AND SOIL. UPON THIS LAND STORMS FELL AND THROUGH IT MULTITUDES OF STREAMS FOUND THEIR WAY TO THE SEA. FLOWING RIVERS CAME FROM THE CLOUD-CAPPED MOUNTAINS......

BUT AI-LAAU STILL POURED OUT HIS FIRE.......

HE LIVED FOR A LONG TIME IN A VERY ANCIENT PART OF KILAUEA, ON THE LARGE ISLAND OF HAWAII IN THE PIT CRATERS, AND WAS SAID TO BE LIVING THERE WHEN PELE CAME TO THE SEASHORE FAR BELOW........

WHEN PELE CAME TO THE ISLAND HAWAII, SHE FIRST STOPPED AT A PLACE CALLED KE-AHI-A-AKA IN THE DISTRICT OF PUNA. FROM THIS PLACE SHE BEGAN HER INLAND JOURNEY TOWARD THE MOUNTAINS. AS SHE PASSED ON HER WAY THERE GREW WITHIN HER AN INTENSE DESIRE TO GO AT ONCE AND SEE AI-LAAU, THE GOD TO WHOM KILAUEA BELONGED, AND FIND A RESTING PLACE WITH HIM AS THE END OF HER JOURNEY. SHE CAME UP, BUT AI-LAAU WAS NOT IN HIS HOUSE. OF A TRUTH HE HAD MADE HIMSELF ENTIRELY LOST. HE HAD VANISHED BECAUSE HE KNEW THAT THIS ONE COMING TOWARD HIM WAS PELE. HE HAD SEEN HER TOILING DOWN BY THE SEA AT KE-AHI-A-LAKA. TREMBLING DREAD AND HEAVY FEAR OVERPOWERED HIM. HE RAN AWAY AND WAS ENTIRELY LOST.......

WHEN PELE CAME TO THAT PIT SHE LAID OUT THE PLAN FOR HER ABIDING HOME, BEGINNING AT ONCE TO DIG UP THE FOUNDATIONS. SHE DUG DAY AND NIGHT AND FOUND THAT THIS PLACE FULFILLED ALL HER DESIRES.......

THEREFORE, SHE FASTENED HERSELF TIGHT TO HAWAII FOR ALL TIME.........."

ADAPTED FROM WILLIAM D. WESTERVELT, HAWAIIAN LEGENDS OF VOLCANOES, COLLECTED AND TRANSLATED FROM THE HAWAIIAN, CHARLES TUTTLE, PUBLISHER, 1963.

Hydrothermal resources are the most common. Energy in these systems (to a depth of about 3 km) can be tapped by current technology. A hydrothermal convection system is created when groundwater adjacent to a magma chamber is heated and rises toward the earth's surface as steam or hot water. Liquid-dominated hydrothermal systems are known to exist in several parts of the United States (including Hawaii) as well as in New Zealand, Japan, and numerous other countries around the world. These reservoirs of warm (90°C-150°C) to very hot (>150°C) water are often confined by low permeability cap rock or by the hydrostatic pressure of overlying layers of cooler groundwater. Vapor-dominated hydrothermal systems are less common. Geothermal fluids in these systems are nearly

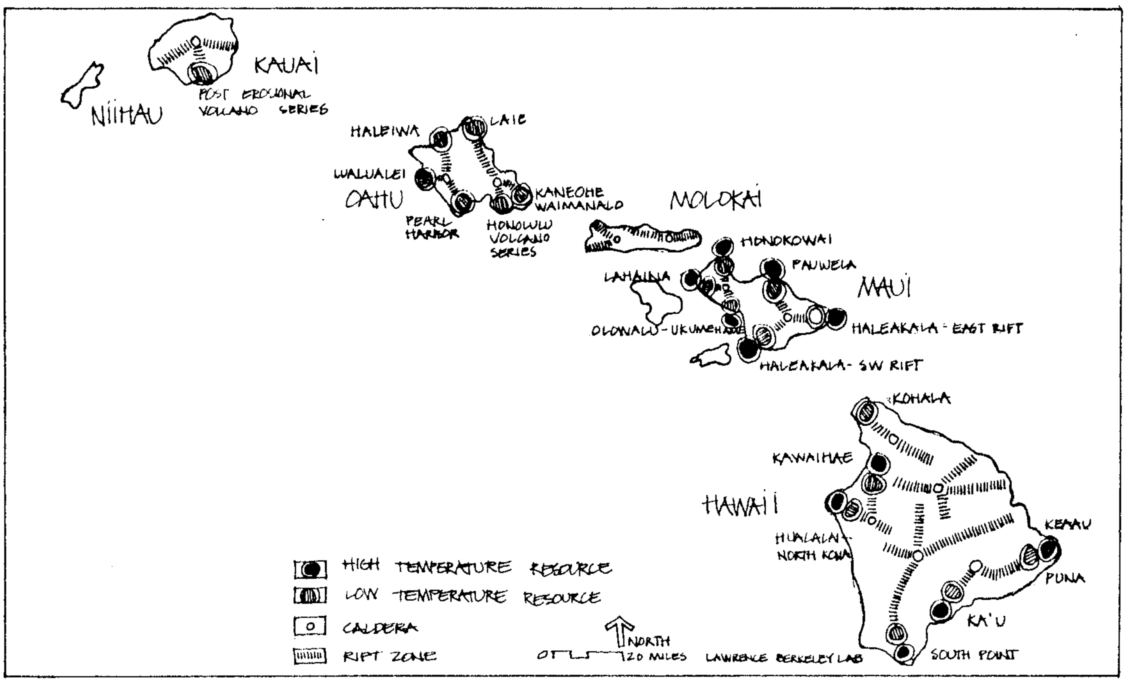


FIGURE 6: POTENTIAL GEOTHERMAL RESOURCE AREAS

Source: D. Thomas, et. al. "Potential Geothermal Resources in Hawaii: A Preliminary Regional Survey," Hawaii Institute of Geophysics, 1979.

longevity. The lifetime of a thermal system will depend on the size of the cooling magma body as well as the rate at which heat is removed.

A preliminary assessment of the potential geothermal resource areas in Hawaii is being carried out by the Hawaii Institute of Geophysics with support from the state legislature and the Department of Energy. Initial compilation of existing geophysical and geochemical data was completed in 1978. About twenty areas were identified as having sufficient geothermal potential to merit more intensive field investigations. Geochemical and geophysical surveys have been completed in some of the targeted areas and are currently underway in several others. The sites with potential for high (>150°C) and low (35-150°C) temperature resources are depicted in Figure 6.

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3. HOW CAN GEOTHERMAL ENERGY BE USED?

THE GEOTHERMAL DEVELOPMENT PROCESS

Geothermal energy is a demonstrated technology which can be adopted to reduce Hawaii's dependence on imported oil. Experience from geothermal development in the western U.S. shows that it takes about nine years to complete a geothermal power plant from field exploration to the operating stage. The time required for a direct use facility will vary with the application selected, the temperature, and the number of wells required to supply the facility. For some agricultural applications, this can be as short as three to four years.

CAPITAL REQUIREMENT

Geothermal applications are relatively capital-intensive compared with conventional fossil fuel power plants. However, this is offset by smaller fuel costs. The competitiveness of a geothermal system can be determined by calculating the potential savings of the system over the expected lifetime of the project. Annual savings can be estimated by comparing annual operating costs of a geothermal system with those of a system using conventional fuels. A geothermal project is economically preferable if the present worth of the geothermal project (annual savings discounted back to present value) is equal to or greater than the additional capital investment required for the project.

In Hawaii, the cost of drilling a production well is estimated to be about $1-1.5 million. Exploration and field development costs alone for a 25 MWe power plant may exceed $6 million. Compared with electric power plants, costs for direct applications are generally less because fewer and shallower wells are required. Because developers cannot earn

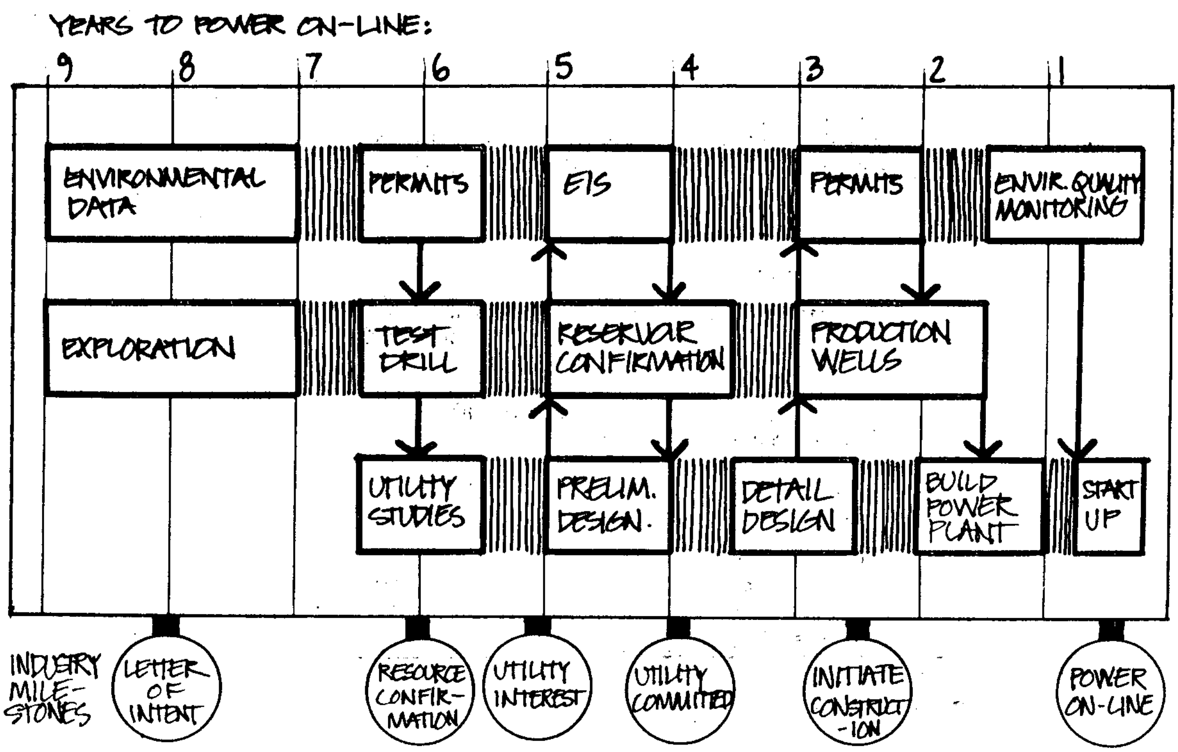

FIGURE 7: GEOTHERMAL DEVELOPMENT PROCESS
Source: Adapted from Jet Propulsion Laboratory, "The Analysis of Requirements for Accelerating the Development of Geothermal Energy Resources," Pasadena, California, 1977.

a return on their investment until the field begins production, they must assess at the outset whether the size of the anticipated energy market justifies the costs of field development.

Figure 7 shows the relationship among different activities in the geothermal development process. Key milestones for private sector participants are identified in the lower portion of the illustration.

QUESTIONS ABOUT ELECTRIC RATES AND GEOTHERMAL ENERGY

Will geothermal energy help to reduce electric bills?

Yes, in the long run. As the costs of fossil fuels continue to rise, the cost for producing electricity from geothermal sources would rise less rapidly. Initial development and equipment costs are higher for geothermal electric power plants than for conventional diesel fuel power plants, but because the cost of operating a geothermal plant is low, electricity rates are more stable over time.

Why is electricity cheaper on Oahu?

The cost of actually delivering electricity to customers on Oahu is cheaper than on the Island of Hawaii. The main factors contributing to this are:

- There are more people per square mile on Oahu which allows a greater sharing of transmission facilities;
- There are less transmission line losses because customers are closer to one another; and
- Crude oil from overseas is shipped to refineries on Oahu, then distributed to the power plants directly. On the Big Island, fuel oil for the power plants must be shipped from the West Coast of the United States or from Oahu.

GEOTHERMAL APPLICATIONS

The costs incurred in transportation of geothermal fluids dictate that a resource be located close to a potential user. Depending on the temperature and quantity of steam or hot water, geothermal resources may meet energy requirements for electricity generation, direct uses, or both. The economics of production and distribution will vary with each reservoir. Applications combining electricity generation and direct heat uses would improve both the economics and the utilization efficiency of a resource.

Electricity generation

Production of electricity for sale to the public is regulated by the Hawaii Public Utilities Commission. At present, the market for electricity is limited on those islands with identified geothermal potential. Each island is a separate market because electricity produced on one island cannot presently be transmitted directly to another.

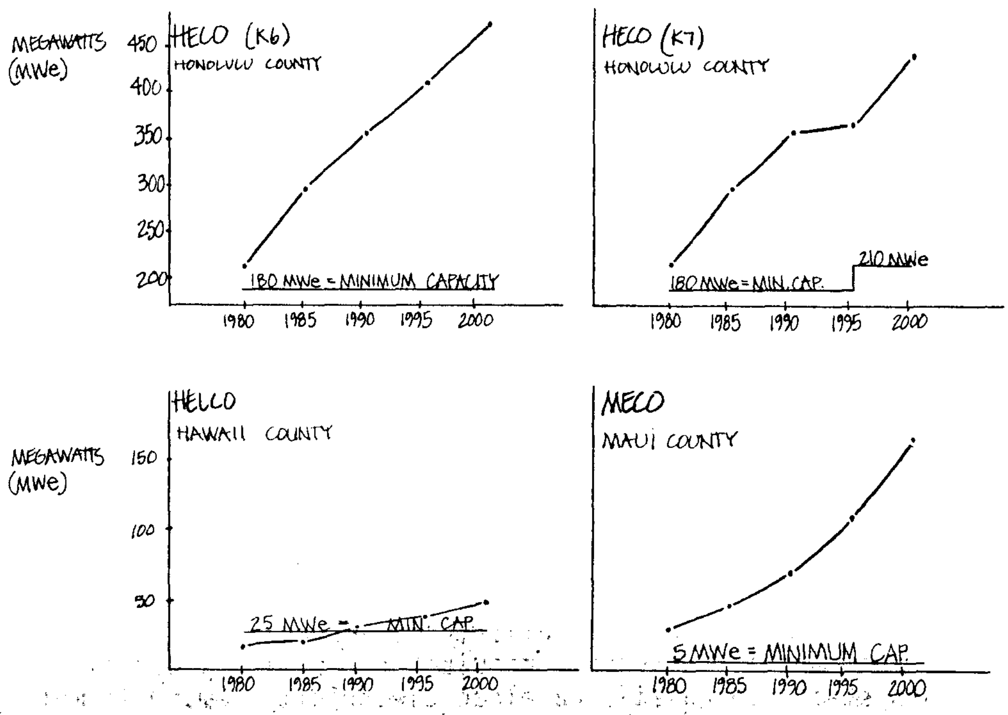

FIGURE 8: WINDOWS FOR GEOTHERMAL ELECTRIC POWER
Source: Hawaiian Electric Company, 1980

Figure 8 shows the potential market for geothermal electricity for the service areas of the Hawaii Electric Company (Honolulu County) and its subsidiaries, Hawaii Electric Light Company (Hawaii County) and Maui Electric Company (Maui County).

On the Big Island, the "window" for electricity derived from all alternate energy sources is about 25 MWe through the year 1990. This represents the total projected market for new generation capacity based on the estimated growth in demand, combined with reduction of existing fuel oil generation capacity to a minimum operating level.

Adoption of a new fuel source by a utility will depend on how well the new energy source meets the overall requirements of its production and transmission system. In Hawaii, baseload electricity demand is met by fuel oil power plants, with intermediate and peak loads supplied by excess electricity produced by sugar mills as part of their milling operations. Electricity generated from geothermal resources is best suited for base and intermediate load electricity requirements because production wells must be operated continuously.

Generation of electricity from geothermal resources can be accomplished in several ways depending upon the temperature and the relative percentage of steam and hot water. Four common types of power plants include (1) those using dry steam, (2) single or multiple flash units using flashed steam, (3) binary plants using a secondary working fluid, and (4) plants which involve a combination of flashed steam and binary technology. A fifth plant type is a hybrid power plant where geothermal resources are used in conjunction with fossil fuels, solar energy, or biomass for electrical generation.

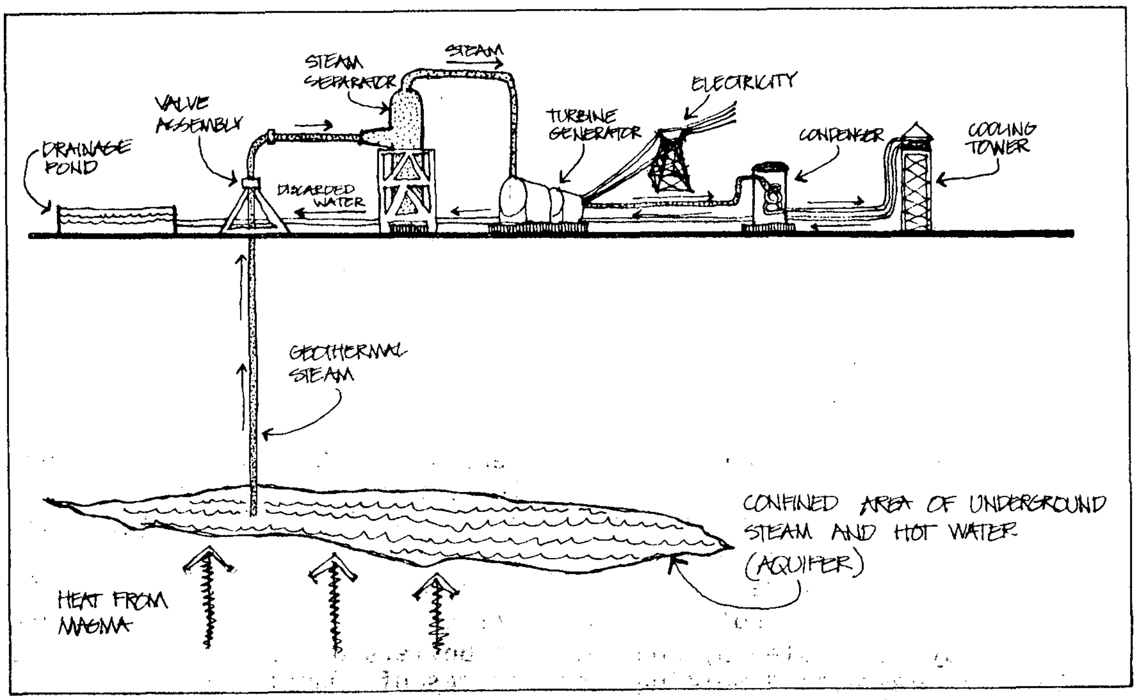

FIGURE 9: THE HGP-A POWER PLANT

Source: Adapted from University of Hawaii, HGP-A Project Bulletin, 1978.

A flashed steam system has been selected for the HGP-A well at the Kapoho reservoir on the Big Island. These power plants rely on steam flashed from superheated water brought to the surface. The efficiency of the plant can often be increased by sequential flashing at progressively lower pressures to obtain the maximum amount of steam from a given volume of water. Once the steam is separated from the water, it is fed into turbines that drive the generators. The remaining water and condensate are usually injected back into the reservoir. Figure 9 illustrates the geothermal power plant at the HGP-A Generator Project.

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Direct Use Applications

Direct use of geothermal energy can be more energy efficient than electricity production. A conversion efficiency of 70 to 90 percent is possible compared with an efficiency of 5 to 25 percent for electricity generation. Resources with temperatures ranging from 10°C to 100°C have been used for commercial and residential hot water heating, space conditioning, industrial processing, agriculture, and aquaculture. Potential direct applications of geothermal heat are shown in Figure 10. Resources below 60°C may be boosted by conventional boilers or by heat recovery systems to meet the desired working temperatures of industrial processes.

Direct heat applications usually require a shorter development time and a smaller initial investment than developments for electricity generation. Drilling can be accomplished at lower costs using conventional water well drilling equipment and technology.

Given the present limited market for electricity on the Big Island, electricity production and direct use applications may be combined to optimize exploration and production. Where the resource exceeds the requirements of the existing market for electricity or direct applications, it may be possible to expand the market by creating or attracting energy-intensive applications, such as pumping water for irrigation or residential consumption, chemical recovery and minerals processing (bauxite or manganese nodules). However, the feasibility of such proposals depends on a complex set of factors including water rights, transportation routes, and local acceptance of the ventures.

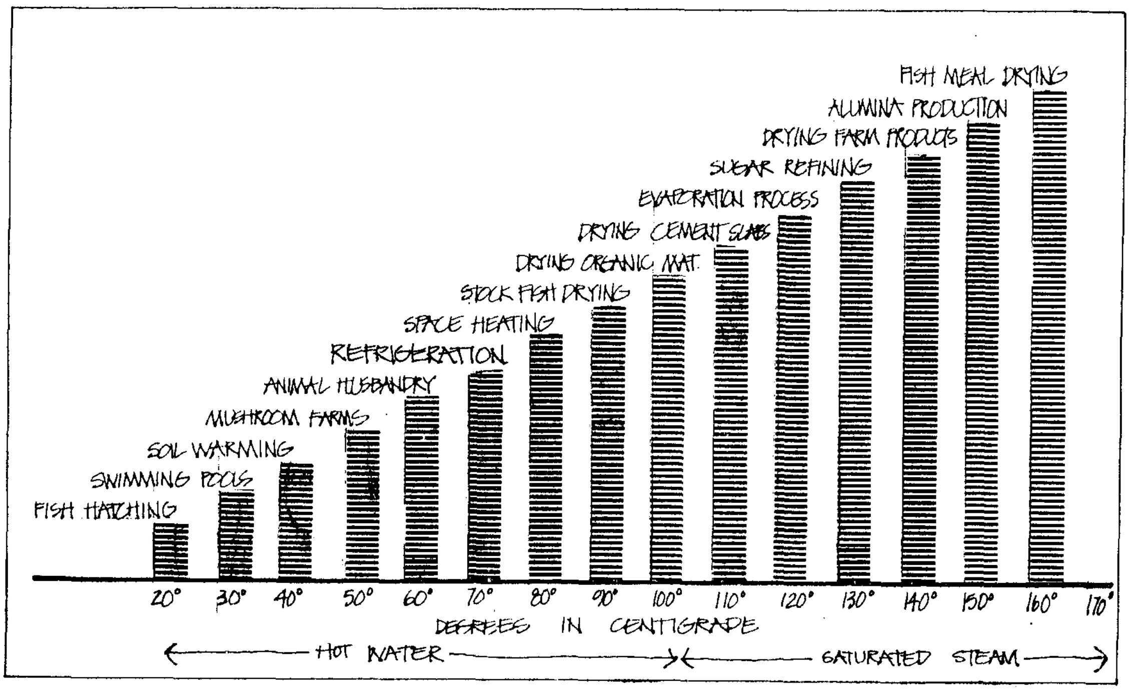
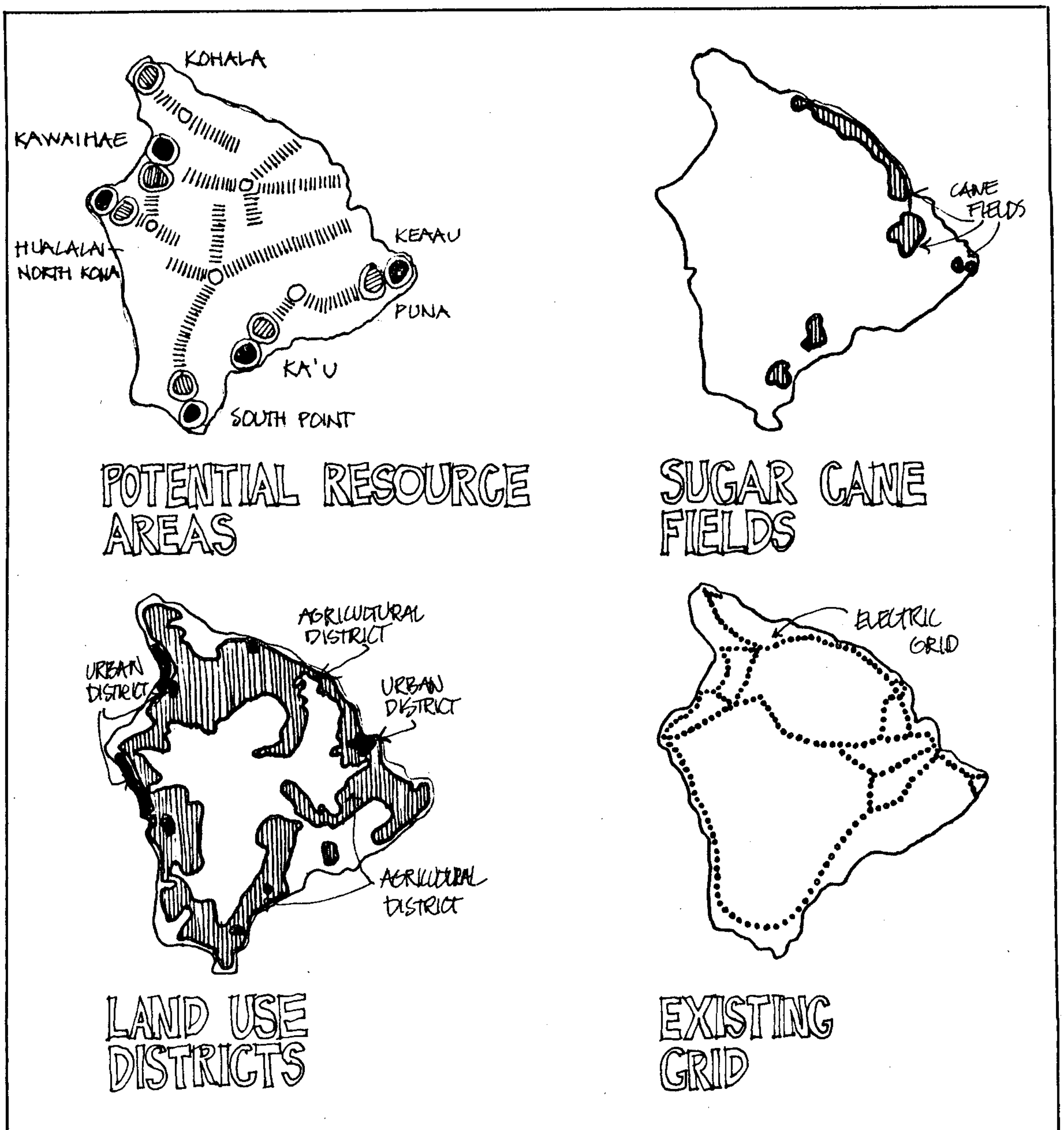


FIGURE 10: DIRECT USE APPLICATIONS OF GEOTHERMAL STEAM
Source: Adapted from Goodman and Love, Geothermal Energy Projects, Pergamon Press, 1980.

Some communities favor direct use applications because more direct benefits (jobs, taxes, buildings) are retained within the community. In addition, if several process heat users are located near a geothermal resource, it is possible to integrate a number of applications with successively lower heat requirements such that the waste heat from one operation can be used as a fuel for another (generally referred to as cascading).


KOHALA
KAWAIHAE
HUALALAI
NORTH KONA
KEAAU
PUNA
KA'U
SOUTH POINT
POTENTIAL RESOURCE AREAS
CANE FIELDS
SUGAR CANE FIELDS
AGRICULTURAL DISTRICT
URBAN DISTRICT
URBAN DISTRICT
AGRICULTURAL DISTRICT
LAND USE DISTRICTS
ELECTRIC GRID
EXISTING GRID

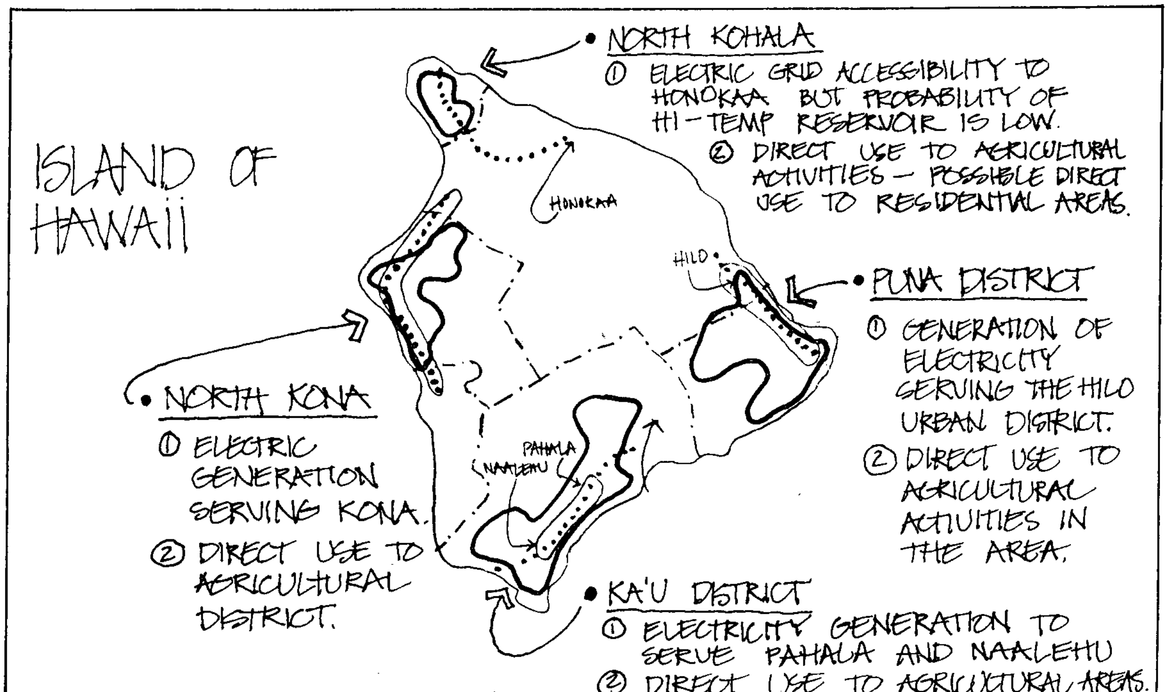


FIGURE 11: POTENTIAL MARKETS FOR GEOTHERMAL POWER ON THE ISLAND OF HAWAII
Source: Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

The County of Hawaii supports geothermal exploration and resource assessment efforts because the availability of an energy resource increases development options for the local area. Figure 11 shows areas on Hawaii where the colocation of potential resource areas, urban settlements, transmission facilities and agricultural centers may encourage the use of geothermal energy.

Electricity Transmission to Neighbor Islands

The utilities and the state are also examining possible development of geothermal resources on the Big Island and Maui to supply baseload electricity to the entire state. This option will depend on the creation of an effective transmission and distribution system that would allow distribution of geothermal electricity to load centers on Oahu. The establishment of an inter-island electricity grid by cable connection would also serve to optimize distribution of power from all alternate energy resources. A proposed route for the inter-island submarine cable between Hawaii and Oahu is shown in Figure 12.

Presently available undersea DC power cables would permit connection among Maui, Molokai, Lanai, and Oahu. However, some advancement in cable technology is needed to develop cables that can withstand depths

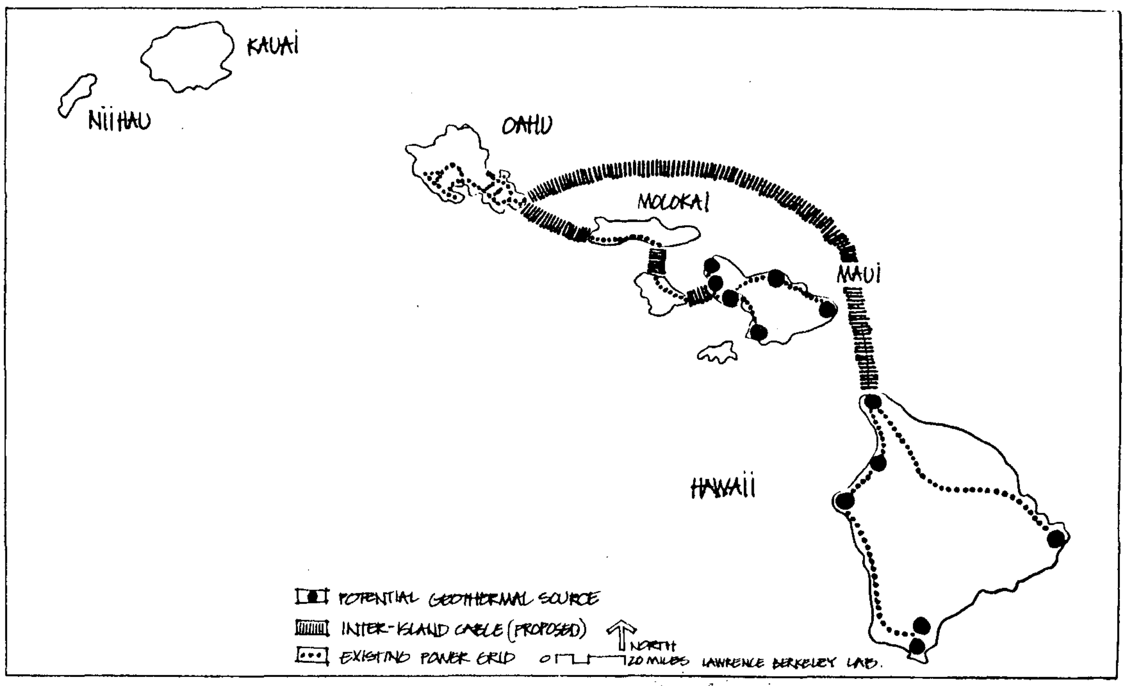


FIGURE 12: PROPOSED INTER-ISLAND SUBMARINE CABLE TRANSMITTING GEOTHERMAL POWER

Source: Parson Engineering (Hawaii); Lawrence Berkeley Laboratory, Geothermal Energy Commercialization Project, 1980.

of 2000 meters to permit interconnection of the island of Hawaii with Maui County and Oahu. A study of the present and potential status of undersea power cables and their use in Hawaii is underway as part of the state's energy program. This project involves design and testing of cables which can be used in depths greater than 2000 meters and of a cable laying ship. While linkage of the electricity grid on the various islands is not probable until 1990, the availability of cable technology which permits electricity transmission from the island of Hawaii to Oahu will expand the importance of geothermal exploration efforts significantly.

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4. GEOTHERMAL PROJECTS IN HAWAII

A number of technical, economic, and environmental studies have been carried out to assess the potential of the Kapoho reservoir (near Puna) on the Big Island and to evaluate the feasibility of alternative geothermal applications. Their findings and recommendations are being reviewed by the U.S. Department of Energy (DOE), state and county agencies, the University of Hawaii, and the private sector. Individual studies are described below.

HGP-A WELLHEAD GENERATOR DEMONSTRATION PROJECT

The objective of this project is to demonstrate the production of electricity in an environmentally acceptable manner from an active rift

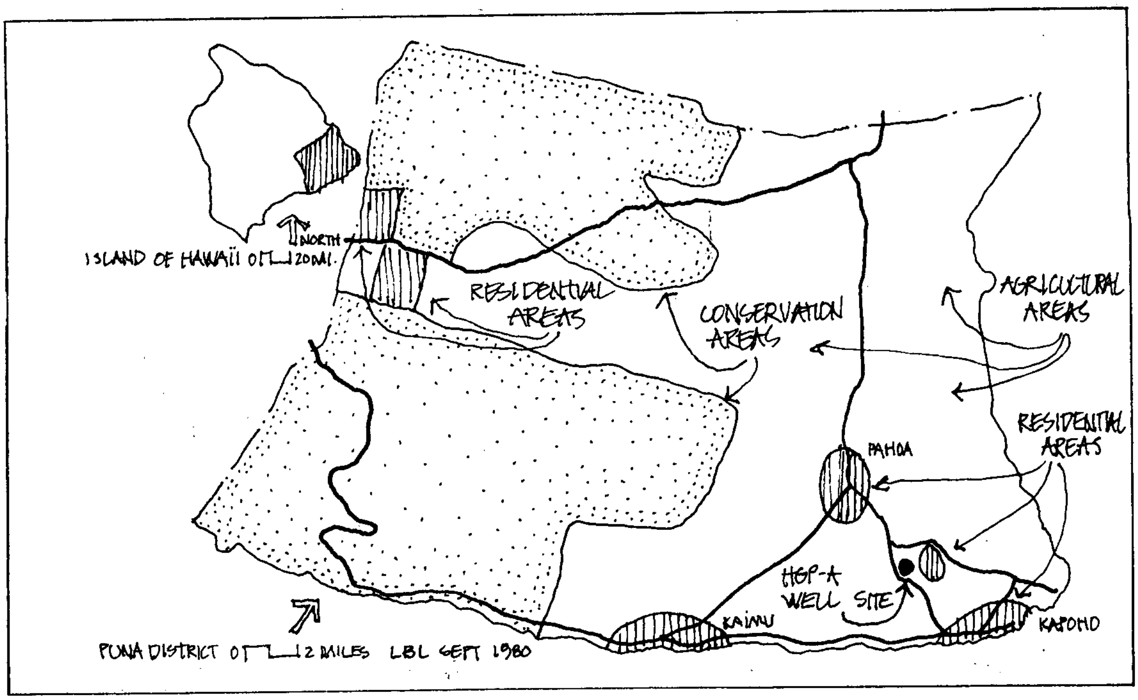

FIGURE 13: LAND USES IN THE PUNA DISTRICT
Source: County of Hawaii - General Plan, 1979.

zone. It is managed by the HGP-A Development Group which includes the State of Hawaii (represented by the Department of Planning and Economic Development), the County of Hawaii, and the University of Hawaii (Hawaii Geothermal Project). The project is funded by the U.S. Department of Energy (84%), with the State (15%) and County of Hawaii (1%), and the Hawaii Electric Light Company (HELCO) (.2%) contributing the remainder.

The HGP-A well is located on a lava flow from the 1955 eruption of Halemaumau. Because of the risk of volcanic eruption occurring near or at the site, the plant is designed so that specific pieces of equipment will be easily removable and transportable. The wellhead assembly is also designed so that it can be protected from lava flows.

The 3 MWe power plant will be operated remotely from HELCO's control room in Hilo. It will use about 0.2 megawatts of the generated electricity for its auxiliary equipment. The remaining 2.8 megawatts will be fed into the HELCO transmission network to provide electricity for the residents throughout the Puna District.

A concerted effort has been made to provide necessary abatement controls to limit air, water, and noise pollution. The architecture and landscaping at the facility are designed to be compatible with the natural surroundings of the site. The location of the wellhead generating facility in Puna and the land uses in the surrounding area are shown in Figure 13. In addition, a comprehensive monitoring program will be carried out by LFE Environmental Analysis Laboratories of Richmond, California.

UTILIZATION OF GEOTHERMAL FLUIDS IN A CANE SUGAR PROCESSING PLANT

DOE has supported technical and economic feasibility studies for direct heat applications since 1977. These studies are made in conjunction with potential users and have included three kinds of applications: industrial process heat (food processing, sugar production, fertilizer production, mineral processing, etc.); district heating (heating systems for communities and smaller users by public or private utilities); and agribusiness and aquaculture (production and processing of food at the farm).

In 1978, DOE funded a proposal by the Puna Sugar Company to evaluate the feasibility of using geothermal fluids from a site near the HGP-A well at a sugar refining plant located some sixteen miles away in Keaau. Figure 14 illustrates the pipeline route used in the feasibility study. The project examined the possibility of substituting geothermal steam for steam generated by the burning of bagasse, which in turn would be used to increase electric power generation.

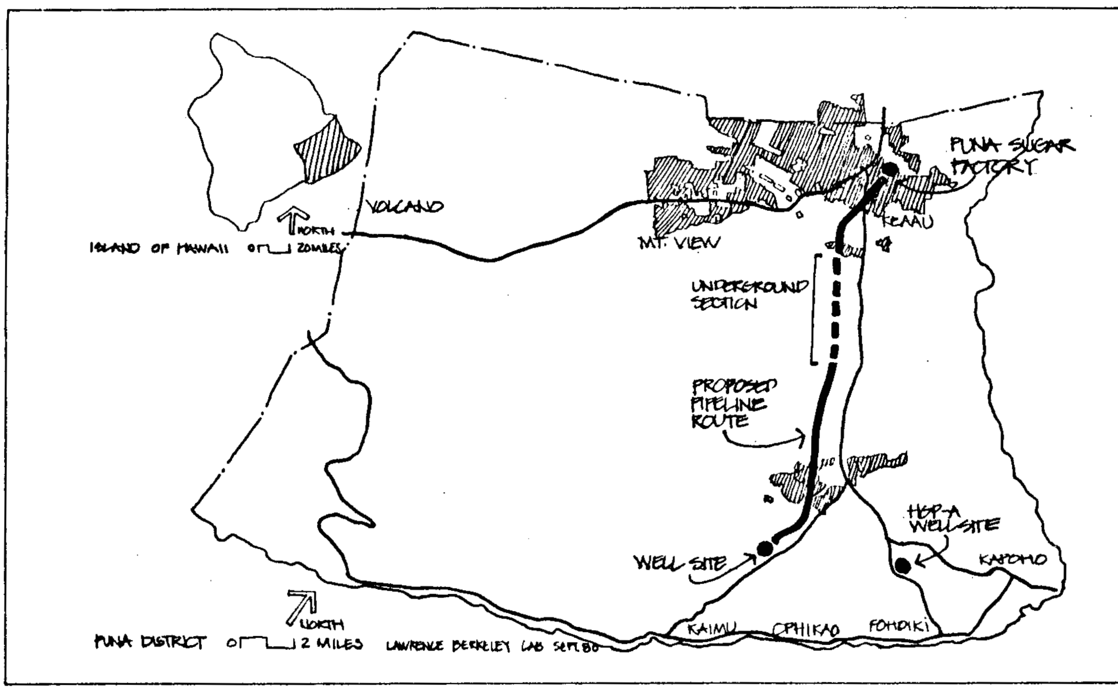

FIGURE 14: FEASIBILITY STUDY—PIPING GEOTHERMAL FLUIDS TO A SUGAR FACTORY AT KEAUU

Source: Puna Sugar Company, AMFAC Inc., "Engineering and Economic Analysis for the Utilization of Geothermal Fluids in a Cane Sugar Processing Plant," July 1979.

The study was completed in February 1979. Figures 15 and 16 are diagrams of the existing sugar refining process and the proposed use of geothermal fluids. The study concluded that use of geothermal heat at the Keaau processing plant is technically feasible but only marginally profitable based on private financing or internal financing by Puna Sugar's parent company. Substantial public economic benefits flowing from the proposed project were identified. Projected royalty payments, taxes, and a lower electricity rate structure would contribute more than $79 million to the community over the 20 year program. The investigators recommended that serious consideration be given to partial government ownership and alternative financing arrangements.

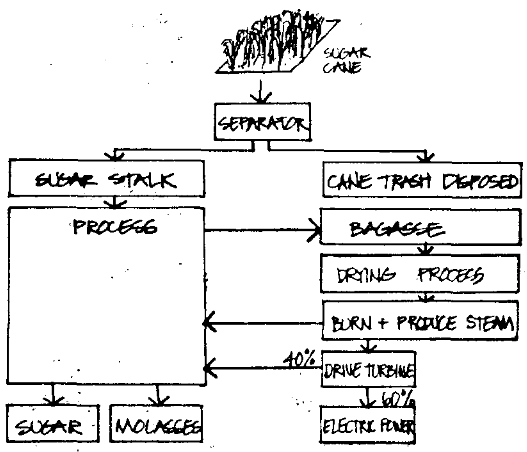

FIGURE 15: SUGAR PROCESSING AND POWER PRODUCTION

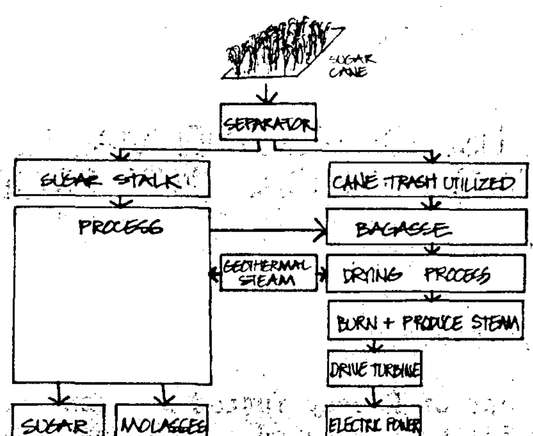

FIGURE 16: USES OF GEOTHERMAL FLUIDS FOR FUEL DRYING AND PROCESS STEAM

Source: Curt Beck, Hirai and Associates, Hilo, Hawaii; Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

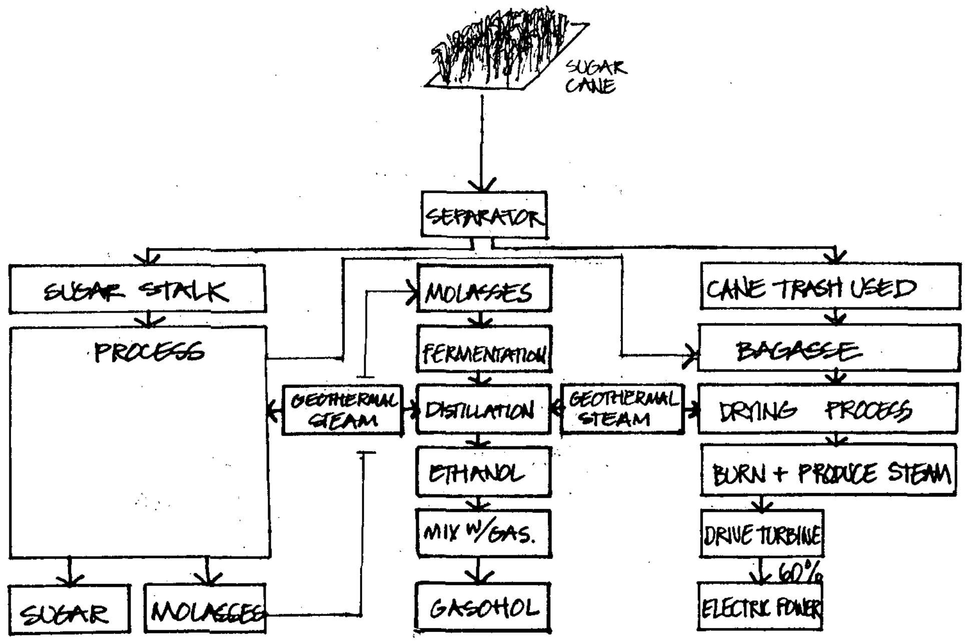

FIGURE 17: USE OF GEOTHERMAL FLUIDS FOR SUGAR PROCESSING AND GASOHOL PRODUCTION
Source: Curt Beck, Hirai and Associates, Hilo, Hawaii; Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

GEOTHERMAL COMMERCIAL PARK

In 1979, the Department of Energy funded a second feasibility study for a geothermal commercial park located near Pahoa, Hawaii. The study examined utilization of geothermal energy as a resource to expand the local mix of agricultural and energy products. Geothermal fluid from a proposed 7,000 foot well will be transported two miles to an 800 acre industrial site located at the western end of the Kilauea East Rift Zone.

Two alternative modes of development were examined. The first is combined development of the geothermal commercial park with development of a 25 MWe power plant. Costs of transmission facilities and wells could be shared. An alternative is to develop wells and transmission facilities for the industrial park independently.

The final concept for the geothermal park includes four industries and a research facility to demonstrate promising direct applications. The anchor industry for the geothermal park will be an ethanol plant producing 20,000 gallons per day of fuel-grade ethanol and gasohol. Figure 17 illustrates proposed uses of geothermal fluids for sugar processing and gasohol production.

Another facility will be a plant that will recover the large protein molecule from the leaf of the leucaena plant using existing technology for recovery of protein from alfalfa. Feedstock for these plants will be bagasse from sugar mills and eucalyptus and leucaena trees grown on nearby energy tree farms.

The third application of interest to the agricultural community is a papaya processing plant using geothermal fluids to cool a warehouse for fresh fruit, a puree production line, and a vacuum dehydration process to make papaya snacks. Success of such a venture will depend on whether local farmers are willing to relocate their processing facilities to the geothermal park and to form the nucleus of a cooperative enterprise.

PUBLIC CONCERNS	POSSIBLE RESPONSES
• Site selection may have negative impacts on surrounding properties	• Alternative site locations and site layouts should be considered
• Social services and local infrastructure (e.g., roads, utilities) will be strained	• Local residents should be trained in needed skills
• Noise levels may increase	• The public should be well informed about geothermal development
• Outsiders may be needed to build, operate and maintain the power plant	• Local investors, community groups, and other interested parties should be included in planning and financing
• Developers may be selfish or insensitive to community concerns	
• Residents may not participate in public hearing procedures	

FIGURE 18: POSSIBLE RESPONSES TO PUBLIC CONCERNS
Source: Adapted from Jim Moreau and W. Lloyd Jones, "Direct Heat Geothermal Opportunities at Pahoa, Hawaii," 1980; Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

The fourth application is a cattle feed mill producing a roughage component for cattle feed using sugar cane leaves combined with a binder, cut and dehydrated. The feed produced can be sold to markets in Hawaii and Japan.

The feasibility study identified a number of concerns about proposed development of a geothermal commercial park. Some residents raised questions about the potential overloading of the two-lane highway near Pahoa and the associated traffic noise. Others objected to specific industries and the introduction of outsiders to operate the industries. Acceptance of the geothermal park as a development option for the community will require that these concerns be resolved in an open dialogue with community, county, and state representatives. See Figure 18, Possible Responses to Public Concerns.

5. BALANCING THE BENEFITS AND COSTS OF GEOTHERMAL DEVELOPMENT

POTENTIAL BENEFITS

Energy Independence

Development of geothermal resources on the Big Island will contribute to the state's goal of reduced dependence on imported fuel. Electricity generated from geothermal resources will help to maintain a lower rate structure in the Island's electricity grid. Over the long term, if geothermal electricity is transmitted to Oahu to meet baseload electricity requirements, it will improve the state's balance of payments.

WHAT GEOTHERMAL ENERGY CAN DO ...

Short Term:

1. Geothermal energy is not a source of firm power until the reservoir is proven. Technically, this is difficult to do.
2. Back-up power sources are therefore required.
3. Geothermal energy can meet process heat requirements for uses that now require electricity or other fuels, for example, agricultural processes.
4. Direct sources of heat may be supplied by geothermal energy to certain industrial, commercial or residential applications, thus reducing utility peak demand.

Long Term:

1. With a proven reservoir, geothermal energy could supply a continuous source of base load electric power for all uses.
2. With a technically feasible submarine cable connecting the more northerly islands to Hawaii, geothermal energy may be able to satisfy electricity demand on Oahu.
3. Where bagasse is now used to supply base load electricty, geothermal energy could be used. This frees up the bagasse for possible conversion to liquid fuels such as gasohol.

Economic Growth

Geothermal resources may also contribute to the competitiveness of goods and services produced in Hawaii by providing a reliable source of energy at stable prices. Employment at direct use facilities may create additional local income, and operating expenditures will benefit the state's economy. In addition, the expansion of the existing agricultural economy on the Big Island to include production of ethanol and cattle feed, as well as processing of sugar cane, papaya, and other fruits, will provide jobs for the local population as well as revenues to support development of community services.

Environmental Tradeoffs

Geothermal power is more environmentally benign than fossil fuel and nuclear power, both of which have been considered as less desirable alternatives to the state's dependence on oil imports than renewable energy resources. A comparative analysis of environmental impacts of power generation from geothermal, wind, biomass, and solar resources is underway in the Hawaii Integrated Energy Assessment Project.

POTENTIAL COSTS AND THEIR MITIGATION

Environmental Concerns

The environmental impact of geothermal development can vary widely depending on the location, scale, and level of development. While individual projects may affect the environment only slightly, the cumulative effect of several applications may be significant. The acceptability of a particular project may depend also on its compatibility with existing or planned activities in the vicinity.

Environmental Quality Standards

While there are no specific standards for geothermal operations, a number of federal environmental quality standards provide reference points for state and local regulatory agencies. Health standards established by the Occupational Safety and Health Administration (OSHA) protect workers from continuous exposure to potentially harmful substances which may result in adverse health effects. These standards are based upon exposure levels of 8 hours per day. The Environmental Protection Agency (EPA) sets ambient air and water quality standards that protect the health of the general population. State and local agencies overseeing geothermal development may adopt additional standards to balance the amount of pollution, costs of mitigation, and the number of persons affected at individual sites. See Appendix B for a list of laws and regulations relating to energy and the environment in Hawaii.

Environmental baseline studies (as part of the HGP-A Project and direct use feasibility studies) provide a useful basis for assessment of environmental impacts flowing from actual development activities. A program of "phase monitoring" is now being directed by University of Hawaii scientists. Under this program, selected emissions and effluents will be monitored regularly before and after the startup of geothermal operations. The frequency and type of measurements will decrease if no significant impacts are discovered.

Potential impacts that have been identified include emissions of gases such as hydrogen sulfide and sulfur dioxide; high noise levels from drilling, well testing, and power plant operation; and mineral or thermal

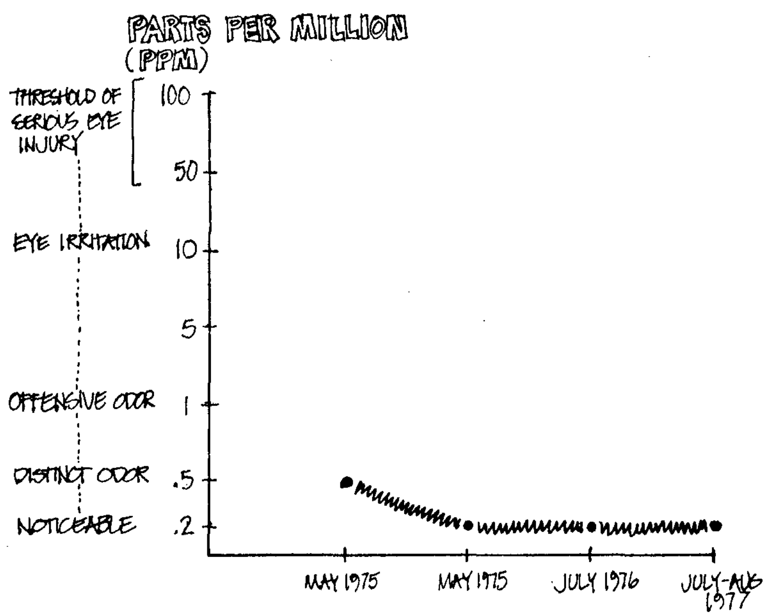

FIGURE 19: HYDROGEN SULFIDE ABATEMENT AT HGP-A
Source: Adapted from Goodman and Love, Geothermal Energy Projects, Pergamon Press, 1980.

pollution of surface or ground waters. Land subsidence from withdrawal of geothermal fluids on the Big Island is regarded as improbable because underlying basalt formations do not depend on geothermal fluids for support. However, because subsidence due to seismicity is a natural phenomenon in the East Rift Zone, the collapse of lava tubes or water table modification are continuing concerns.

Air Quality

The primary concern for air quality is focused on hydrogen sulfide, sulfur dioxide, and mercury. The results of the well tests for HGP-A indicate that present abatement technology is capable of maintaining emissions from well operations within requirements set by the EPA. See Figure 19, H_2S Abatement at HGP-A.

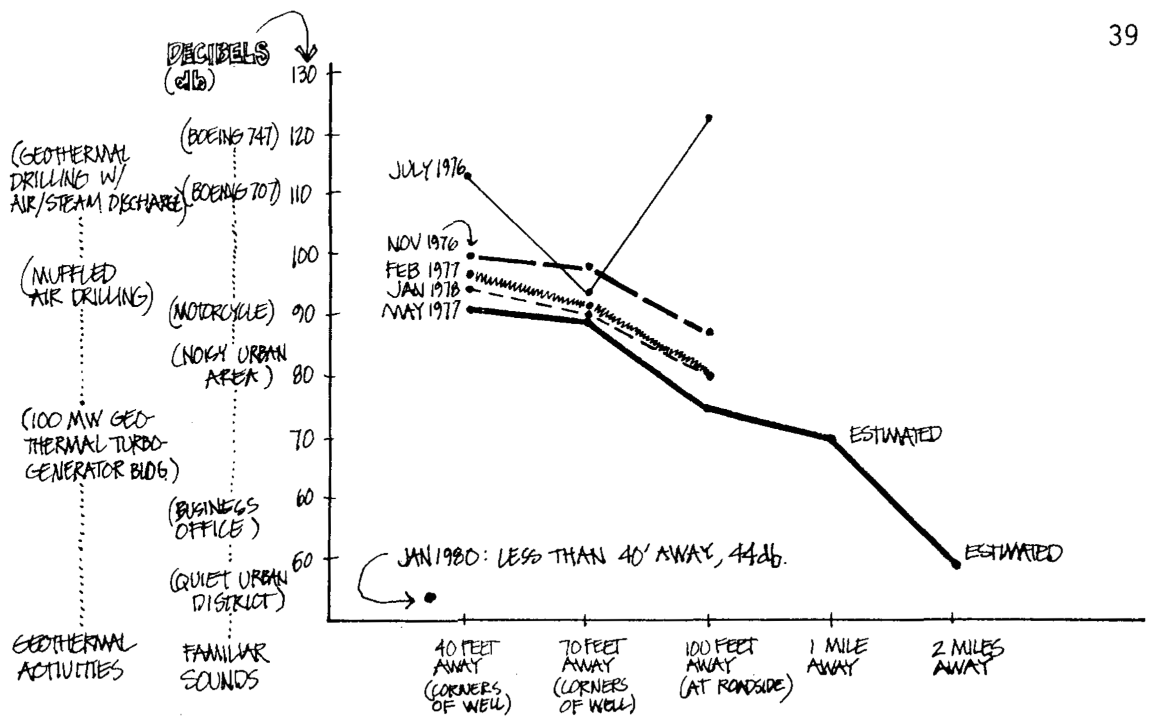

FIGURE 20: HGP-A NOISE CHARACTERISTICS

Source: Adapted from Goodman and Love, Geothermal Energy Projects, Pergamon Press, 1980. Hawaii Institute of Geophysics.

Noise

During the initial phases of field development, persons in the vicinity of a geothermal site may be exposed to noise levels varying from 40 to 120 decibels, depending upon the distance from the well site. High noise levels are produced well drilling, production testing, bleeding before connection to the generator. While most operations can be effectively muffled by acoustical baffling and rock mufflers, some emit unavoidable noise.

The design standard for the HGP-A Wellhead Generator Project specifies that the noise level one-half mile from the well site must be no greater than 65 decibels. Construction of a rock muffler at the facility has reduced noise levels to about 44 decibels at the fence line of the project. See Figure 20, Noise Characteristics at HGP-A.

IN PARTS PER MILLION (PPM)

	SILICA (SiO_2)	CHLORIDE (CL)	SODIUM (Na)	POTASSIUM (K)	CALCIUM (Ca)	MAGNESIUM (Mg)	SULFIDE (SO_4)
DEPOSITS FOUND IN SEPARATOR	873	2930	1700	248	17.9	≤ 10	73.6
DEPOSITS FOUND IN SEAWATER	4	19,500	9600	398	450	1290	2200
DEPOSITS IN 15% SEAWATER	0.6	2925	1440	60	68	194	330

FIGURE 21: DISSOLVED SOLIDS IN HGP-A EFFLUENTS
Source: Donald Thomas, Hawaii Institute of Geophysics, 1980.

Water Quality

Contamination of surface or groundwater from geothermal operations is of substantial concern to regulatory agencies. Migration of salt water into the surrounding groundwater table during the drilling of a geothermal well can be prevented by careful casing and grouting practises. Very minimal effects on groundwater quality are expected if established drilling requirements are followed.

The environmental effects of geothermal fluids discharged during well testing and production will vary with the types and concentrations of salts dissolved in the effluent and choice of well site. Dissolved solids contained in the effluent from the HGP-A project are listed in Figure 21. For purposes of comparison, the concentrations of the same elements found in sea water and a diluted (15%) solution of seawater similar to the brackish groundwater found at the HGP-A site are also presented. Groundwater in the area surrounding HGP-A is not potable because of seawater intrusion. Effluent from the power plant will be piped to a settling pond to remove dissolved silica and then percolated into the ground or used for irrigation.

Land Use.

In the Puna area, the major determinant of land use and infrastructure requirements will be development of proposed subdivisions. The anticipated level of geothermal development (25-50 MWe) in the near term will not produce significant adverse impacts on existing residential or agricultural uses.

Community Aesthetics

The cumulative effect of environmental impacts on the life-style of surrounding communities is an important consideration. Effects of proposed development on the economic, social, and cultural experience of the community are examined collectively as part of the comprehensive planning and permiting process at the local level.

To address this issue, DOE has funded two social impacts studies of geothermal development in Hawaii. These studies provide an opportunity for the Native Hawaiian population in Puna to examine the environmental and social consequences of geothermal development along with county, state, and federal agencies. They supplement the environmental, institutional, and legal assessments for the HGP-A Project and the direct use feasibility studies.

Social Impacts Assessment, Puna Hui Ohana

A grant made to the Puna Hui Ohana (a Native Hawaiian community association) will provide baseline data for cultural concerns which may be affected by geothermal development in the Puna area. The Hui has established a geothermal library in the community and conducted a number of geothermal symposia for Puna residents. Preliminary results of an attitudinal survey indicate that the majority of the Native Hawaiian population in the Puna area favors geothermal development if it is properly planned and if the community has an adequate opportunity to review the potential costs and benefits.

Environmental Overview

An Environmental Overview of geothermal development in Hawaii was also funded by DOE to assess the cumulative economic, environmental, legal, and social impact of geothermal development in the state. This project was carried out as a joint effort between Lawrence Livermore Laboratory and the University of Hawaii. The researchers concluded that no major impacts would follow from the present level of development at the HGP-A well. They recommended site-specific studies for geothermal activities in other areas because one study for a single facility cannot provide sufficient data for extrapolation. The final report for the Overview Study has been completed. It contains recommendations for further actions to address environmental, institutional and regultory issues associated with future development.

Figure 22 summarizes the potential environmental impacts and mitigation measures for a 3 MWe power plant and a cane sugar processing plant.

POTENTIAL IMPACTS	IMPACT OF 3 MEGAWATT POWER PLANT (HGP-A)	CANE SUGAR PROCESSING PLANT
Hydrogen Sulfide	Scrubber devices at wellhead .... eliminate this problem.	Same as for 3 megawatt power plant.
Sulphur Dioxide	Under evaluation; existing .... emissions are within permitted levels.	Same.
Mercury	Higher than normal levels .... of mercury already present in areas of volcanic activity.	Same.
Disturbance to .... Plants/Animals	No effect on identified .... endangered species	Same.
Noise	Silencers and rock mufflers .... placed at wellhead lower noise levels.	Buffered by vegetation and buildings; acceptable levels at nearest property line.
Visual Intrusion	No significant impact	Minimized by remoteness of facility; screened by topography and vegetation.
Hawaiian Cultural .... Sites	No impact from existing .... well location.	Same.
Land Subsidence	Believed to be very .... improbable.	Same.
Erosion/Sedimentation	May be avoided by careful .... siting of operations and facilities.	Same.
Induced Seismic .... Activity	Under evaluation	Same.

FIGURE 22: POTENTIAL ENVIRONMENTAL IMPACTS FROM GEOTHERMAL DEVELOPMENT

Source: Environmental Impact Statement for HGP-A Project, 1979; Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

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6. MAKING GEOTHERMAL POWER A REALITY

THE FEDERAL ROLE

Geothermal energy is recognized as a technologically ready and economic source of energy. The goal of the federal geothermal program is to maximize use of the nation's geothermal resource in an environmentally and socially acceptable manner and to demonstrate that it can make a significant contribution toward regional energy requirements and as a replacement for imported fuels.

The present federal effort includes programs which provide: support for resource confirmation, support for technology development, support for cost sharing demonstrations, technical assistance to the private sector, planning assistance to state and local governments, and loan guarantees for private development. In addition, the Geothermal Energy Act of 1980

(Title VI of the Energy Security Act) will provide $85 million nationwide for resources exploration and confirmation loans and $5 million for economic feasibility studies.

Policies of federal agencies for geothermal development are coordinated through the Interagency Geothermal Coordinating Council (IGCC), with the Division of Geothermal Energy (DGE) in the Department of Energy having primary responsibility for implementation of the program. The functions of various federal agencies are shown Figure 23.

STATE POLICIES FOR GEOTHERMAL DEVELOPMENT

Geothermal energy is considered to be a real energy and development option for Hawaii. This has come about through active cooperation between the private sector, government agencies, and the University of Hawaii.

AGENCY	IMPROVE RESOURCE ESTIMATES	LEASING OF FEDERAL LANDS	REDUCE COSTS AND RISKS (R & D)	PRODUCE ENERGY	STIMULATE ENERGY DEVELOPMENT	REGULATE ENERGY PRODUCTION
Department of Energy (DOE)						
Resource Assessment	Yes	Yes	Yes	Cost shared demonstrations.	Set commerciali- goals; geothermal loan gurantee program (GLGP).	Prepare EAR/EIS for DOE projects.
Environment			Yes			Review EAR/EIS.
Federal Energy Regulatory Commission						Power production decisions on geothermal projects.
Energy Research			Yes			
Department of Commerce (DOC)						
Economic Development Administration				Yes	Yes	
Department of Defense (DOD)			Yes	Yes		
Department of Housing and Urban Development (HUD)				Yes	Yes	
U.S. Department of Agriculture (USDA)						
Forest Service		Yes		Yes	Yes	Process non-competative lease applications; review permits.
Department of Transportation (DOT)					Yes	
Department of the Interior (DOI)						
Bureau of Land Management (BLM)		Yes	Yes (Bureau of Mines)			Environmental review before leasing.
U.S. Geological Survey (USGS)	Yes	Yes	Yes			Monitor environmental impacts after leasing.
Fish and Wildlife Service (FWS)						Yes
Water and Power Resources Service (WPRS)	Yes					
Environmental Protection Agency (EPA)			Yes			Environmental regulations

(Table adapted from IGCC, Fourth Annual Report to Congress, June 1980, Tables IV.3 and IV.4)

FIGURE 23: RESPONSIBILITIES OF FEDERAL AGENCIES IN GEOTHERMAL DEVELOPMENT

Source: Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

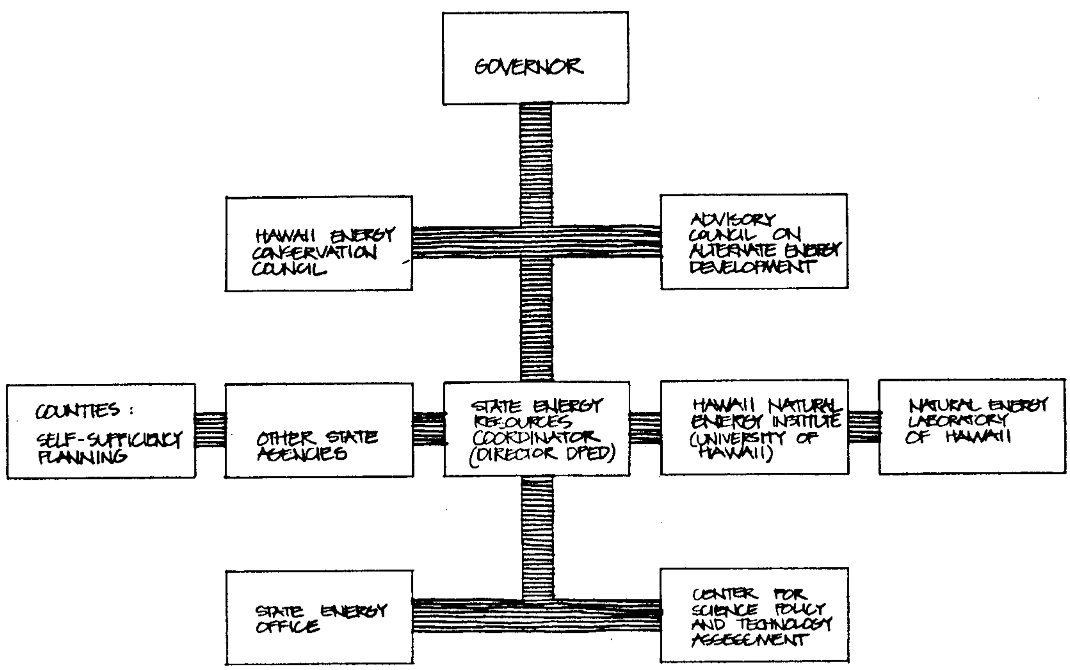

FIGURE 24: ENERGY ORGANIZATION

Source: Department of Planning and Economic Development, State Energy Plan, 1980.

Figure 24 shows the state energy organization. The Energy Resources Coordinator oversees the energy programs of the state as mandated by the Governor and the Legislature. The Hawaii Natural Energy Institute carries out research and development efforts for alternate energy resources and coordinates counties' energy self-sufficiency programs. In the Department of Planning and Economic Development, the Center for Science Policy and Technology Assessment (CSPTA) is responsible for the commercialization of most alternate energy resources. Two advisory committees have been set up to assist CSPTA in the area of geothermal energy. The HGP-A Development Group is a consortium composed of state, country, university, and industry representatives. Their task is to advise and manage the Wellhead Generator Project. The Geothermal Advisory Committee reviews ongoing development activities and makes recommendations for legislation and other state initiatives. See Appendix C for a list of group members.

The environmental impacts assessment process, which includes the various permitting processes and preparation of environmental baseline studies and environmental impact statements, is the procedure by which government agencies balance the trade-off between the costs and the benefits of a specific project. A number of state agencies regulate geothermal development. The Department of Land and Natural Resources oversees leasing of state lands for geothermal exploration, and for drilling activities on both private and public land. The Department of Health enforces regulations for air quality. County planning commissions and the State Land Board will review proposed development activities to ensure conformity with state and county land use plans.

WHO OWNS GEOTHERMAL ENERGY?

In 1974, the Hawaii State Legislature declared geothermal to be a mineral resource. Under this characterization, the state of Hawaii owns geothermal resources under state lands (approximately 38% of the state) as well as those private lands where the mineral rights have been expressly reserved to the state. Following the state's declaration, two ownership issues have arisen. What is the extent of state claims to geothermal resources under private lands where there is no express or implied mineral reservation to the state? What is the extent of Native Hawaiian claims to geothermal resources and development revenues?

The Geothermal Commercialization Project (see discussion below) is reviewing both legal and policy aspects of these questions. While the question of resource ownership has not directly affect exploration activities to date--developers have been willing to deposit lease payments and royalties in an escrow account pending the resolution of the issues--the controversy over resources ownership is extremely volatile because of the land-constraint environment of the Islands. Important policy considerations are whether development on public and private lands should proceed in the same way, the equity of Native Hawaiian claims, and administrative feasibility of particular options available to the state.

COMMERCIALIZATION ISSUES AND GOVERNMENT INITIATIVES

Development of geothermal energy on the Big Island has begun with the announcement of a two year, $5 million exploration program by the Geothermal Exploration and Development Company. The Dillingham Corporation has also received permits from the County of Hawaii to drill two exploration wells in the vicinity of the present HGP-A well. Further impetus to geothermal development will be provided by the forthcoming issuance by Hawaiian Electric Company and the Hawaii Electric Light Company of a request for a proposal to construct a 25 MWe geothermal power plant. Construction of the plant will meet the expected growth in electricity demand on the island to the year 1990. Geothermal development beyond this point is anticipated in conjunction with direct use applications. As the resources are established, further development may involve the introduction of energy-intensive industries or applications, or the export of electricity to Oahu. Potential high-temperature resources have also been identified on the Island of Maui. As of this writing, an exploration company is interested in drilling some wells on the island to establish the resource potential.

A comparison of the different levels of geothermal development is presented in Figure 25.

LEVEL OF GEOTHERMAL DEVELOPMENT	IMPLICATIONS Social	Economic	Technical	Environmental	Time Frame
1. No geothermal	Keeps Hawaii in ... extremely vulnerable position with respect to fuel supply.	Continued escalation of electricity rates.	Undue reliance .... on less proven energy resources.	None	Can be implemented within 1 year.
2. Maintain HGP-A as .... a test facility	As above .... Enhances community awareness of an alternative energy option.	As above	Could supply useful data for geothermal operations in Hawaii and USA.	Minimal	Operating now
3. Small scale 25-50 .... megawatt power plant and direct use operations	Provides some ..... jobs.	Bagasses from ..... sugar could be made into ethanol; other applications may include a cattle feed mill, protein recovery plant, processing of papayas Could satisfy Big Island electric needs to 1990.	Technology is ..... available now; can tie to HELCO grid.	Minimal; measures . could be found to virtually eliminate impact.	2-5 years
4. Medium scale 50-100 ..... megawatt power plant and direct use operations	As above .... Potential lifestyle changes. Planning is required to insure that development is consistent with community goals.	As above .... New small to moderate scale industries are possible.	Technology is ..... available now; can tie to HELCO grid.	Moderate; measures are available to substantially reduce impact.	5-15 years
5. Large scale 100- .... 300 megawatt power plants and direct use operations	As above	Could substantially reduce the State's dependence on foreign oil. Will stabilize electric rates. Will involve the relocation of energy intensive industries. Will accelerate economic development on the Big Island.	Inter-island ...... cable required; technology is available but not proven - study now underway	Substantial; ...... extensive measures required to reduce impact.	15-20 years

FIGURE 25: IMPLICATIONS FROM DIFFERENT LEVELS OF GEOTHERMAL DEVELOPMENT

Source: Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

UNCERTAINTIES	FEDERAL	STATE	LOCAL
TECHNICAL			
RESOURCE RELIABILITY RESOURCE ASSESSMENT	TECHNICAL SUPPORT AND FUNDING (DOE)	TECHNICAL SUPPORT AND FUNDING	SUPPORT FOR RESOURCE ASSESSMENT; MARKET INFORMATION
ECONOMIC			
RETURN ON INVESTMENT FRONT-END CAPITAL	TAX INCENTIVES; LOAN GURANTEES TO PRIVATE FIRMS.		
LEGAL			
RESOURCE RIGHTS	ASSIST STATE AND LOCAL GOVT. IN DEFINING	LEGISLATIVE ACTION TO DEFINE OWNER RIGHTS	
MANAGERIAL			
PLANNING AND MANAGEMENT	TECHNICAL SUPPORT TO STATE AND LOCAL GOVT.	TECHNICAL SUPPORT; INFORMATION TO LOCAL GOVT.	
ENVIRONMENTAL			
LEVEL OF IMPACT	TECHNICAL ASSISTANCE AND INFORMATION DISSEMINATION	LEGISLATION FOR PERMITS AND ENVIRONMENTAL REVIEWS	PROVIDES LOCAL REVIEW PROCESS; PUBLIC HEARINGS; RECOMMENDATIONS
SOCIAL			
PUBLIC UNDERSTANDING ACCEPTABILITY COMPENSATION	INFORMATION DISSEMINATION; WORKSHOPS AND SYMPOSIA; DIRECT GRANTS TO LOCAL ORGANIZATIONS (DOE)	INFORMATION; WORKSHOPS AND SYMPOSIA; COMPENSATION TO IMPACTED COMMUNITIES IF REQUIRED BY LAW	CAN PROVIDE DIRECT ASSISTANCE TO IMPACTED COMMUNITIES AND NEIGHBORHOODS IF REQUIRED BY LAW

FIGURE 26: GOVERNMENT ACTIONS TO REDUCE GEOTHERMAL DEVELOPMENT UNCERTAINTIES

Source: Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

Many technical, economic, environmental, and institutional uncertainties attend this first generation of geothermal development. See Figure 26, Government Actions to Reduce Geothermal Development Uncertainties. Together with the federal government, the state has sponsored a number of geothermal projects to help resolve or reduce these uncertainties so that the promise of geothermal energy may be realized. Figure 27 describes the relationship of individual projects to geothermal issues. The goals, participating organizations, as well as the results to date of these projects are presented in Figure 28, Status of Geothermal Projects in Hawaii.

UNCERTAINTIES	1 HEP-A	2 RESOURCE ASSESSMENT	3 ELECTRIC CONDUCT.	4 ROCK INVEST.	5 HEAT EXCHANGE	6 RESERVOIR TESTING	7 HIEA	8 GCP	9 SOCIAL IMPACT	10 ENVIRON. OVERVIEW	11 INDUST. PK STUDY	12 WELLHEAD GENERATOR	13 STATE ENERGY PLAN
TECHNICAL													
RESOURCE RELIABILITY	●	●	●	●	●	●						●	
RESOURCE ASSESSMENT	●	●	●	●	●	●		●			●	●	
ECONOMIC													
RETURN ON INVESTMENT								●			●		
FRONT-END CAPITAL								●			●		
LEGAL													
RESOURCE RIGHTS	●								●				
MANAGERIAL													
PLANNING AND MANAGEMENT							●	●			●		●
ENVIRONMENTAL													
LEVEL OF IMPACT	●							●	●	●			
SOCIAL													
PUBLIC UNDERSTANDING								●	●	●			
ACCEPTABILITY								●	●	●			
COMPENSATION									●	●			

FIGURE 27: STATE PROJECTS TO REDUCE GEOTHERMAL DEVELOPMENT UNCERTAINTIES

Source: Adapted from Department of Planning and Economic Development, State Energy Plan, 1980; Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

In addition to the technology development efforts directed by the Hawaii Natural Energy Institute there are two other noteworthy projects that will support geothermal energy development in the State.

The <u>Geothermal Resources Assessment Program</u> is supported jointly by the U.S. Department of Energy and the state of Hawaii. Surface exploration activities are being conducted under the management of the Hawaii Institute of Geophysics, to identify both high (>150^{o}C) and low (35^{o}C-150^{o}C) temperature areas in the state. Total funding for the project is $225,000 per year.

CURRENT PROJECTS	PROJECT GOALS	PARTICIPATING ORGANIZATIONS*	RESULTS TO DATE
1. Hawaii Geothermal Project (HGP-A)	Demonstrate feasibility of Puna reservoir; drill a successful well with producing potential.	DOE, GEDCO, HIG, RCUH	Successful well drilled; geophysical engineering and socio-environmental studies completed; impacts identified.
2. Resource Assessment	Improve assessment capability.	DOE, HIG	Mapping of potential high and low temperature resources.
3. Electrical Conductivity Studies	Improve assessment capability.	HIG, HNEI	Underway.
4. Basaltic Rock Investigations	Improve assessment capability.	DOE, HIG, HNEI	Underway.
5. Heat Exchanger Studies	Improve assessment capability.	DOE, HNEI	Underway.
6. Reservoir Synthesis	Improve assessment capability.	DOE, HIG, HNEI	Underway.
7. Hawaii Integrated Energy Assessment Project (HIEA)	Energy alternatives identified and compared.	DOE, DPED, LBL	Preliminary report completed.
8. Geothermal Commercialization Project	Identify barriers to commercialization of geothermal energy.	DOE, DPED, ERA, Hirai Associates, Matteson and Rae, Parsons Hawaii, Don Thomas.	Underway.
9. Geothermal Social Impact Studies	Determine social impact of geothermal development on native Hawaiians in Puna.	DOE, Alu Like, Puna Hui Ohana.	Underway.
10. Geothermal Environmental Overview	Assess environmental impacts from geothermal development.	DOE, HNEI, LLL, RCUH	Preliminary report completed.
11. Geothermal Commercial Park	Direct use industrial applications for geothermal energy.	DOE, DPED, Dillingham, Merrill Lynch, Parsons.	Ethanol plant, protein recovery plant, papaya processing plant, cattle feed mill identified as technically feasible applications.
12. Puna Wellhead Generator Project	Develop 3 megawatt electric power plant.	DOE, DPED, County of Hawaii, HECO, HELCO, HNEI, HIG, RCUH.	Underway.
13. State of Hawaii Energy Plan	Management plan to implement energy policy objectives.	DPED	In preparation.

* PARTICIPATING ORGANIZATIONS

1. DOE: Department of Energy
2. DPED: Department of Planning and Economic Development
3. ERA: Energy Research Associates
4. GEDCO: Geothermal Exploration and Development Co.
5. HECO: Hawaii Electric Company
6. HELCO: Hawaii Electric Light Company
7. HIG: Hawaii Institute of Geophysics
8. HNEI: Hawaii Natural Energy Institute
9. LBL: Lawrence Berkeley Laboratory
10. LLL: Lawrence Livermore Laboratory
11. RCUH: Research Corporation of the University of Hawaii

FIGURE 28: STATUS OF CURRENT PROJECTS

Source: Adapted from Department of Planning and Economic Development, State Energy Plan, 1980; Lawrence Berkeley Laboratory, Geothermal Commercialization Project, 1980.

The areas in which surveys have been conducted on the Island of Hawaii include Kawaihae, Hualalai northwest rift, Kailua Kona, Mauna Loa southwest rift, Kilauea lower east rift, and Keaau. On Maui, geological, geochemical, and geophysical surveys are underway in the northwest rift zone of Haleakala (Haiku-Paia) and the Lahaina-Kaanapali area. Extensive geochemical surveys have also been carried out in the Lualualei Valley on Oahu. The resource assessment effort in the next two years will expand to include South Point and Ka'u on the Big Island, Olowalu-Ukumehame and southwest Haleakala area on Maui, and also the area surrounding Kaneohe Marine Corps Air Station on Oahu. Although these surveys are limited to surface investigations, it is hoped that as evidence of geothermal potential is established, both the public and private sectors will take an active part in the confirmation of the resource areas.

The Center for Science Policy and Technology Assessment is directing a Geothermal Commercialization Project to evaluate the near term public and private sector requirements for geothermal development. The project serves as a focal point for exchange of information among the local community, industry, and the various state agencies responsible for geothermal activities. It will make recommendations to the legislature for economic incentives, geothermal research and development, and appropriate regulatory and public information programs.

Geothermal power will become a reality on the Island of Hawaii in 1981 with the commissioning of the HGP-A Wellhead Generator Unit. Continued cooperation between the industry, the University, and the county, state, and federal governments is necessary to ensure that development takes place in a timely manner to meet the state's goals for energy independence. The future success of geothermal energy, measured by its contribution to the state's economic and social well-being, will depend on the informed participation of the people of Hawaii, both as individuals and as representatives of the private and public sectors.

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APPENDIX A. GLOSSARY OF TECHNICAL GEOTHERMAL TERMS

A more extensive glossary of technical terms may be found in C.S. Letter, Jr. and R.A. Ersinberg, Geothermal Handbook, The John Hopkins University, June 1977.

AA
A type of granular volcanic rock, the native Hawaiian name.

AQUIFER
A water-bearing layer of porous rock, sand, or gravel.

ARCHIPELAGO
A group of islands, especially when scattered over an expanse of sea.

BAFFLE
A device, such as a wall or screen, for directing or deflecting movement of fluids or sound.

BAGASSE
Remains of sugar cane after the juice has been extracted by pressure; used to supply the fuel requirements of raw sugar mills.

BALNEOLOGY
Science of the healing qualities of baths, especially natural mineral waters; the therapeutic use of natural warm or mineral waters.

BARREL (OIL)
A unit of volume equivalent to 42 U.S. Standard gallons.

BASALT
A fine-grained igneous rock dominated by dark-colored minerals, usually magnetic.

BASELOAD ELECTRICITY GENERATION
Electricity power supplied on a continuous and fixed basis, to supply at least minimum system demand, i.e. that which is always needed.

BINARY THERMAL ARRANGEMENT
Transfers geothermal heat to a second fluid, which is used to drive the power production process.

BIOMASS
Any organic material, with specific reference to organic material that has the potential for use as a fuel.

BLOWOUT PREVENTER
A device used to prevent the escape of oil, water, or gas when a pressurized pocket is penetrated by a drill.

BOILING POINT
The temperature at which a liquid changes phases into a gas, at a particular pressure.

BOREHOLE
A hole drilled into the earth, often to a great depth.

BRINE
A highly salty solution.

BRITISH THERMAL UNIT (Btu)
The amount of heat required to raise the temperature of a pound of water $1^{o}F$ at its point of maximum density.

CALDERA
A large volcanic depression, circular in form, with a diameter many times greater than the volcanic opening.

CALORIE
The quantity of heat needed to raise 1 gram of water $1^{o}C$.

CAP ROCK
A relatively dense layer of rock that prevents the circulation of heat or fluids.

CAPITAL
(1) Machinery, tools, etc. used to produce a commodity, as distinguished from labor, fuel or raw materials. (2) The money necessary to purchase such machinery.

CAPITAL-INTENSIVE
Having a high proportion of total costs associated with initial machinery, tools, etc., relative to operating costs of labor, fuel, and materials.

CASCADING UTILIZATION
Sequential use of thermal energy, where the waste heat of one use provides the input heat to another.

CHEMICAL GEOTHERMOMETER
A technique of assessing the temperature characteristics of geothermal reservoirs prior to drilling. Most widely used geothermometers are the SiO_2 content and Na, Ca, and K ratios measured in water samples.

COGENERATION SYSTEM
Energy use system in which fuel provides both electricity and process heat.

CONDENSER
A device for reducing gases or vapors to liquid or solid form.

CONDUCTANCE (CONDUCTIVITY)
A common way to express general mineral content of water. It is a measure of the capacity of water to conduct an electrical current under standard test conditions. Conductivity increases as concentrations of dissolved and ionized constituents increase. It is actually measured as resistance but reported as conductivity in micromhos.

CONDUCTION
The transference of heat through a medium or body driven by a temperature difference and involving no motion of the medium.

CONVECTION
Transfer of heat from one place to another by actual motion of the heated material (usually a fluid).

DIKE
A body of igneous rock that cuts across the structure of adjacent rocks. Most dikes result from the intrusion of magma into fissures within the original formation.

DIRECT USE APPLICATIONS
Use of heat source directly, rather than converting to electricity before use.

DRILLING MUD
A suspension, generally liquid, used in rotary drilling. It is pumped downward through drill pipe to seal off porous zones and to counterbalance the pressure of oil, gas, and water.

DRILL PIPE
Pipe to which the bit is attached and which is rotated by a drill. Drilling fluid circulates through the pipe.

DRY ROCK
Rocks beneath the earth's surface that contain no trapped water from any source.

EFFICIENCY
The ratio of the useful energy output of a machine or other energy-converting plant to the energy input.

EFFLUENT
(1): Something that flows out, as an outflowing branch of a main stream or lake (2): Waste material (as smoke, liquid industrial refuse, or sewage) discharged into the environment, especially when considered a pollutant.

ELECTRICAL SURVEY
Measurements made at or near the earth's surface, of natural or induced electrical fields; used for mapping mineral concentrations or basement formations.

ELECTROMAGNETIC PROSPECTING
A geophysical method that uses the generation of electro-magnetic waves at the earth's surface to penetrate the earth and contact conducting formations or ore bodies. Currents are induced in the conductors which provide the source of new waves that radiate from the conductors and are detected by instruments at the surface.

ENTHALPY
The heat content of a body or system.

ENTROPY
A measure of the unavailable energy of a system.

FAHRENHEIT
A temperature scale in which the melting point of ice is 32 degrees above zero and the boiling point of water is 212 degrees above zero.

FAULT
A fracture or fracture zone in rock along which there has been displacement of the sides relative to one another parallel to the fracture.

FLASH STEAM
The steam generated when the pressure on hot water (usually above 100°C) is reduced.

FLUID
Having the characteristics of liquids and gases, capable of conforming to the shape of its containers.

FOSSIL FUEL
A deposit of organic material containing stored solar energy that can be used as fuel. The most important are coal, natural gas, and petroleum.

FRACTURE POROSITY
Porosity resulting from the presence of openings (cracks) produced by the breaking or shattering of an otherwise hard rock.

GENERATION CAPACITY
The nominal power output of a production facility, often measured in watts, or Btu per hour.

GEOLOGIC MAP
A map showing surface distribution of rock varieties, age relationships, and structural features.

GEOPHYSICAL PROSPECTING
The mapping of rock structures by methods of experimental physics; included are the measurements of magnetic fields, the force of gravity, electrical properties, seismic wave paths and velocities, radioactivity, and heat flow.

GEOPRESSURED
Placed under pressure by the weight of overlying rock formations.

GEOTHERM (GEOISOTHERM)
An imaginary surface within the earth along which the temperature is

GEOTHERMAL ENERGY
The internal energy of the earth, available as heat from heated rocks or water.

GEOTHERMAL GRADIENT
The rate of increase of temperature in the earth with depth. The gradient near the surface of the earth varies depending on the heat flow in the region and on the thermal conductivity of the rock.

GEOTHERMAL RESOURCE BASE
All of the stored heat in the earth.

GEOTHERMAL RESOURCES
Stored heat that is recoverable using current or near-current technology. The United States Geological Survey limits geothermal resources to heat in the earth above 15^{o}C, to a depth of 10km.

GEYSER
A spring that throws forth intermittent jets of heated water or steam. The heat is thought to result from the contact of groundwater with hot rock.

HEAT
That form of energy that is transferred between two bodies as a result of the difference in temperature, governed by the laws of thermodynamics.

HEAT EXCHANGER
A device for transferring heat from one fluid to another. The fluids are usually (but not necessarily) separated by conducting walls.

HEAT FLOW
Dissipation of heat coming from within the earth by conduction or radiation, measured at the earth's surface.

HEAT FLOW UNIT
One heat flow unit is equal to 1×10^{-6} cal/cm^2-s.

HIGH TEMPERATURE RESERVOIR
Reservoirs hotter than 150°C.

HOT IGNEOUS SYSTEM
A system in which the thermal anomaly is derived from igneous formations in the upper 10km of the crust.

HOT ROCK
Pertains to any rock that is volcanically or radiogenically heated.

HOT SPRING
A thermal spring whose water has a higher temperature than that of the human body (98.6oF).

HOT WATER SYSTEM
A system that is dominated by circulating liquid that transfers most of the heat and largely controls subsurface pressures. Often characterized by hot springs that discharge at the surface.

HYDROFRACTURE
Process of increasing the permeability of strata near a well by pumping in a mixture of water and sand under high pressure. The hydraulic pressure opens cracks, and introduced sand serves to keep them open after the pressure is reduced.

HYDROLOGY
The science that deals with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

HYDROTHERMAL
Of, or relating to, hot water, or hot water dominated geological systems.

HYDROTHERMAL CONVECTION SYSTEMS
In such a system most of the heat is transferred by the convective circulation of water or steam rather than by thermal conduction through solid rock.

IGNEOUS ROCK
Rock formed from a melt or magma by cooling and solidification.

JOULE
The unit for all forms of energy or work in the metric systems. The joule is equal to 1 newton-meter, 1 watt-second, or 1 $kg\text{-}m^2/s^2$. The calorie is defined as 4.1868 J.

kWh (KILOWATT-HOUR)
The amount of energy equal to 1 kilowatt for 1 hour. It is equivalent to 3,412 Btu.

LAVA
Fluid rock that issues from a volcano or a fissure in the earth's surface; also the same material solidified by cooling.

LAVA TUBE The tunnel left from a lava flow in which the edges cooled to form a hard shell, while material in the center flowed away.

MAGMA
Molten rock material within the earth, the cooling of which produces an igneous rock.

MEGAWATT
One million watts or one thousand kilowatts.

METAMORPHIC ROCK
An igneous or sedimentary rock that has partially or completely recrystallized in response to elevated temperature and pressure, e.g. from nearby magma.

METHANE
A colorless, odorless, inflammable gas which is the simplest paraffin compound; formula CH_4 Methane is the main component in natural gas.

MILLIGRAM PER KILOGRAM (mg/kg) A measure of concentration of a substance in a solution. One mg/kg means that for every kg of the solution, the dissolved substance contributes one mg.

OTEC
Ocean Thermal Energy Conversion utilizing the temperature difference between warm surface ocean water and cool deep ocean water.

PAHOEHOE
A type of smooth volcanic rock, the native Hawaiian name.

PARTS PER MILLION (PPM)
A measure of the concentration of a substance in a fluid. A one ppm concentration of a substance means that one of every one million molecules in the fluid is of the specified type.

PEAK LOAD
The highest portion of demand, usually that occurring less than 10% of the time.

PERMEABILITY
The permeability of a rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter. It is measured by the rate at which a fluid of standard viscosity can move a given distance through a given interval of time. The unit of permeability is the darcy.

POROSITY
The ratio of the aggregate volume of interstices in a rock or soil to its total volume; usually stated as a percent.

REINJECTION (INJECTION)
The process of pumping waste water back into a well or aquifer.

RESERVOIR
A natural underground container of liquids, such as oil, water, or gases.

RIFT ZONE
A system of fractures and faults in the earth's crust.

SALINITY
The quantity of total dissolved salts in water.

SEDIMENTARY
Descriptive term for rock formed from sediment.

SEDIMENTARY BASIN
A geologically depressed area with thick sediments in the interior and thinner sediments at the edges.

SEISMIC
Pertaining to an earthquake or earth vibration, including those that are artificially induced.

SEPARATOR
A shaped pipe near the well-head that separates the hot water from the steam that is used in the electrical turbines.

SHALE
A layered sedimentary rock in which the particles are mainly of clay grade.

SILENCER
A simple wide vertical tube that deflects the geothermal steam skyward and lowers the pitch of the noise.

SPACE HEATING
The process of supplying the required heat for the physical comfort in houses, offices, or enclosed industrial plants.

STEAM
The vapor into which water is converted when heated to the boiling point; a vapor arising from a heated substance.

STRATUM
(1): Section of a formation that consists throughout of approximately the same kind of rock material (2): A single sedimentary bed or layer, regardless of thickness (plural strata).

SUBSIDENCE
A local sinking of the earth's surface with little or no horizontal movement. This vertical movement can be caused by natural processes such as earthquakes or by man-made withdrawal of deep fluids which support surface formations.

TECTONIC
Of, pertaining to, or designating the rock structure and external forms resulting from the deformation of the earth's crust.

THERMAL EFFICIENCY
The ratio of the energy (heat or work) achieved by a system or device to the heat input to the system or device.

THERMAL GRADIENT
The rate of increase or decrease in temperature with distance in a specified direction.

TWO-PHASE FLOW
The flow of substance or substances in which both liquid and vapor phase are present.

VAPOR DOMINATED
A geothermal system in which pressures are controlled by vapor rather than by liquid.

WATER TABLE
The surface between the "zone of saturation" and the "zone of aeration"; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

WELL-HEAD GENERATOR
An electrical generator attached to the geothermal well pipe, along with the separator and silencer.

APPENDIX B. LEGISLATION AND REGULATIONS APPLICABLE TO GEOTHERMAL DEVELOPMENT

ENACTED INCENTIVES FOR GEOTHERMAL DEVELOPMENT*

ACT, HAWAII REVISED STATUTES	DESCRIPTION
Act 241 (Section 182-1) Section 182-1, HRS), 1974	Resources Management: Expands the definition of "minerals" in the law reserving all mineral rights to the State, to include all geothermal resources,and of "mining operations" to include the development of all geothermal resources.
Act 189 (Section 246-34.7), 1976	Property Tax: Property tax exemption for building improvements which use geothermal energy.
Act 102 (Chapter 269), 1977	Utility Regulations: Exempts nonfossil power generation and transmission facilities from PUC regulation when energy used by producer or sold directly to public utility. Authorizes PUC to require public utilities to purchase surplus power from such facilities.
(Chapter 182, HRS), 1978	Resource Management: Amends the Act 135, law relating to state mineral rights and mineral rights lessees. Amends the law relating to reimbursements for damages due to mining operations, public auction of mining leases, the number of leases.

Authorizes the board to order owner or lessees of land and natural rights on adjoining property to adopt and operate under a cooperative or unit plan of development. Adds a penalty provision for violation of any law or rule relating to the government mineral rights.

Provides that the levy and assessment of the general excise tax on the gross proceeds from sale of geothermal resources or electrical energy shall be a tax on the business of a producer at the rate of 1/2 of 1 percent.

Act 62, 1979	Geothermal Depletion Allowances: Adopts for the purpose of the Hawaii income tax, the provisions of the Internal Revenue Code in effect on December 31, 1978 as they relate to determining gross income, adjusted gross income, ordinary income and loss, and taxable income. (By virtue of the foregoing State's action, the federal depletion allowances including those established by the 1978 Federal Act for geothermal deposits also apply to the state income tax for tax years beginning after December 31, 1978.)

* Reference: National Conference of State Legislatures.

STATE ENVIRONMENTAL LAWS AND REGULATIONS

GENERAL ENVIRONMENT

Laws

Environmental Quality Law, Hawaii Revised Statutes, Chapter 342.

Environmental Quality Commission Law, Hawaii Revised Statutes, Chapter 343.

Environmental Quality Control Law, Hawaii Revised Statutes, Chapter 341.

Environmental Policy Act, Hawaii Revised Statutes, Chapter 344.

Regulations

Environmental Quality Commission, Rules of Practice and Procedure, Effective June 2, 1975.

Environmental Quality Commission, Environmental Impact Statement, Regulations.

AIR POLLUTION

Laws

For Air Laws, see laws listed above under General Environment.

Regulations

Air Pollution Control, Public Health Regulations, Chapter 43, Effective 1973.

Ambient Air Quality Standards, Public Health Regulations, Chapter 42.

ENDANGERED SPECIES

Laws

Hawaii Revised Statutes, Chapter 195D

Regulations

Regulation 6, Division of Fish and Game, Department of Land and Natural Resources, Relating to Issuances of Permits for Capture, or Possession or Destruction of Wild Birds.

LAND USE

Laws

Land Use Law, Including Powers of the Land Use Commission.
Hawaii Revised Statutes, Chapters 174, 181, 183, 184, 205, 205A and 206.

NOISE

Laws

For Noise Laws, see laws under General Environment, above.

Regulations

Vehicular Noise Control for Oahu, Public Health Regulations, Chapter 44A, Effective 1972.

Community Noise Control for Oahu, Public Health Regulations,, Chapter 448, Effective April 26, 1976, Department of Health, Application for Community Noise Permit.

PESTICIDES

Laws

Hawaii Pesticide Law, Hawaii Revised Statutes, Chapter 149A.

RADIATION

Laws

For Radiation Laws, see laws under General Environment, above.

Regulations

Radiation Protection, Public Health Regulations, Chapter 33, Effective 1960.

SOLID WASTE

Laws

For Solid Waste Laws, see laws under General Environment, above.

Regulations

Sewage Treatment and Disposal Systems, Public Health Regulations, Chapter 38, Effective 1973.

Solid Waste Management, Public Health Regulations, Chapter 46, Effective 1974.

WATER POLLUTION

Laws

For Water Laws, see laws under General Environment, above.

Regulations

Department of Health, Application for Permit for Waste Discharge.

Water Pollution Control, Public Health Regulations, Chapter 37.

Water Quality Standards, Public Health Regulations, Chapter 37-A. Effective 1974.

Conservation Standards, Public Health Regulations, Chapter 37-B, Effective 1974.

APPENDIX C. THE GEOTHERMAL COMMUNITY: A DIRECTORY

This appendix is a partial list of organizations involved with geothermal commercialization in Hawaii. The authors are indebted to Messrs. L.Kajiwara, M. Cox, and D. Thomas of the Hawaii Institute of Geophysics for their contributions. For a more extensive listing, readers should consult to their forthcoming Geothermal Directory which will describe the interests and activities of a broader group of governmental and private organizations.

FEDERAL AGENCIES

Department of Agriculture, Forest Service

Charles Hodges, Jr., Director
Institute of Pacific Islands Forestry
1151 Punchbowl Street, Room 323
Honolulu, Hawaii, 96813

U.S. Department of Energy

Dr. Takeshi Yoshihara
P.O. Box 50168
U.S.Dept. of Energy
Honolulu, Hawaii 96850

Mr. John Crawford
Geothermal Program-Region IX
Office of the Regional Representative
U.S. Department of Energy
333 Market Street
San Francisco, Ca. 94105

Environmental Protection Agency

Vicki Tsuhako, Information Specialist
P.O. Box 5003
300 Ala Moana Blvd., Room 1302
Honolulu, Hawaii 96850
(808) 546-8910

Geological Survey

Robert W. Decker, Scientist-in-Charge
Hawaiian Volcano Observatory
Hawaii National Park, Hawaii 96718
(808) 967-7328

Wendell Duffield
Regional Office
345 Middlefield Road, MS 18
Menlo Park, California 94025
(415) 323-8111; 323-2680

Benjamin L. Jones, District Chief
Water Resources Division
P.O. Box 50166
300 Ala Moana Blvd., Room 6110
Honolulu, Hawaii 96850
(808) 546-8331

HAWAII STATE ORGANIZATIONS

HGP Advisory Committee

Mr. David Butchart
Dept. of Land and Natural Resources
State of Hawaii
Post Office Box 621
Honolulu, Hawaii 96809

Mrs. Alma Cooper
Congress of the Hawaiian People
163 Kaiulani Street
Hilo, Hawaii 96720

Dr. John P. Craven, Dean
Marine Programs
University of Hawaii
Holmes Hall 401
Honolulu, Hawaii 96822

Mr. Hideto Kono, Director
Director
Dept. of Planning and Economic Development
State of Hawaii
Post Office Box 2359
Honolulu, Hawaii 96804

Mr. Herbert T. Matayoshi
Mayor
County of Hawaii
25 Aupuni Street
Holi, Hawaii 96720

Dr. Robert I. Tilling
Scientist-in-Charge
Hawaiian Volcano Observatory
U.S. Geological Survey
Hawaii National Park, Hawaii 96718

Mr. Carl H. Williams, President
Hawaiian Electric Company
Post Office Box 2750
Honolulu, Hawaii 968803

State Geothermal Advisory Committee

Dr. Bill Chen
Associate Professor of Engineering
University of Hawaii-Hilo Campus
P.O. Box 1357
Hilo, Hawaii 96720
(808) 961-9367

Mr. E.C. Craddick, President
Geothermal Exploration and
Development Corporation
2828 Paa Street, Suite 2085
Honolulu, Hawaii 96819
(808) 839-7720

Mr. James G. Dittmar
Business Development Manager
Parsons Hawaii
P.O. Box 29909
Honolulu, Hawaii 96820
(808) 836-2061

Dr. Charles E. Helsley, Director
Hawaii Institute of Geophysics
University of Hawaii
HIG 131
Honolulu, Hawaii 96822
(808) 948-8760

Mr. E. Chipman Higgins
Director, Energy Supply
Hawaiian Electric Company
P.O. Box 2750
Honolulu, Hawaii 96803
(808) 548-7721

Mr. W. Lloyd Jones
Manager, Energy Projects
Hawaiian Dredging and Construction
Company
P.O. Box 3468
Honolulu, Hawaii 96801
(808) 735-3211; 735-3275

Mr. Everett Kinney
Puna Hui Ohana
P.O. Box 611
Pahoa, Hawaii 96749
(808) 965-9140

Mr. Hideto Kono
(ex-officio)
Department of Planning and
Economic Development
P.O. Box 2359
Honolulu, Hawaii 96804
(808) 548-3033

Mr. Melvin Koizumi
Deputy Director for Environmental
Program
Department of Health
P.O. Box 3378
Honolulu, Hawaii 96801
(808) 548-4139

Mr. Daniel Lum, Chief
Geology-Hydrology Section
Water and Land Development Division
Department of Land and Natural Resources
1151 Punchbowl Street
Honolulu, Hawaii 96813

Mr. Ralph Masuda
Environmental Specialist
Planning Department
County of Maui
200 South High Street
Wailuku, Hawaii 96793
(808) 244-7723

Mr. Steve Morse, Director
Native Hawaiian Self-Sufficiency
Institute
48-239 Waiahole Valley Road
Kaneohe, Hawaii 96744
(808) 239-7110

Mr. George T.H. Pai, Esquire
Chuck & Pai
1022 Bethel Street, Suite 200
Honolulu, Hawaii 96813
(808) 533-6294

Dr. John W. Shupe, Coordinator
Office of Energy Research
University of Hawaii
Holmes Hall 240-B
Honolulu, Hawaii 96822
(808) 948-8366

Mr. Myron Thompson, Trustee
Bishop Estates
P.O. Box 3466
Honolulu, Hawaii 96801
(808) 523-6200
Attn: Edward Nakamura

Mr. Johnson Wong
Deputy Attorney General
Attorney General's Office
State Capitol Building
Honolulu, Hawaii 96813
(808) 548-3133

Dr. Paul Yuen, Director of HNEI
Hawaii Natural Energy Institute
College of Engineering
University of Hawaii
Holmes Hall 240-F
Honolulu, Hawaii 96822
(808) 948-7886; 948-7727

Department of Budget and Finance
Public Utilities Commission

Albert Tom, Chairman
1164 Bishop Street, Suite 911
Honolulu, Hawaii 96813
(808) 548-3990

Department of Hawaiian Home Lands

Francis Ching
P.O. Box 1879
550 Halekauwila Street
Honolulu, Hawaii 96805

Department of Health

Shinji Soneda, Chief
Enviromental Protection and Health
Services Division
P.O. Box 3378
1250 Punchbowl Street
Honolulu, Hawaii 96801

Ralph K. Yukumoto, Chief
Pollution Technical Review Branch
Environmental Protection and Health
Services Division
P.O. Box 3378
1250 Punchbowl Street
Honolulu, Hawaii 9680
(808) 548-6410

Department of Labor and Industrial Relations

Gordon Frazier, Economist
P.O. Box 3680
825 Mililani Street
Honolulu, Hawaii 96811
(808) 548-3904

Wayne Mount, Administrator
Divison of Occupational Safety and Health
677 Ala Moana Blvd., Suite 910
Honolulu. Hawaii 96813
(808) 548-4155

Department of Land and Natural Resources

Susumu Ono, Chairman
Board of Land and Natural Resources
P.O. Box 621
1151 Punchbowl Street
Honolulu, Hawaii 96813
(808) 548-6550

Libert K. Landgraf, State Forester
Divsion of Forestry and Wildlife
P.O. Box 621
1151 Punchbowl Street
Honolulu, Hawaii 96813
(808) 548-2861

James J. Detor, Administrator
Division of Land Management
P.O. Box 621
1151 Punchbowl Street
Honolulu, Hawaii 96809
(808) 548-2574

Department of Planning and Economic Development

James Woodruff, Geothermal Project Manager
Center for Science Policy and
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250 South King Street
Honolulu, Hawaii 96804
(808) 548-2483

Gordon Furntani, Executive Officer
State Land Use Commission
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190 South King Street, Suite 1795
Honolulu, Hawaii 96813
(808) 548-4611

Department of Regulatory Agencies

Roy Terada, Chief Engineer
Public Utilities Division
P.O. Box 541
1010 Richards Street
Honolulu, Hawaii 96809

Department of Taxation

George Freitas, Director
425 Queen Street
Honolulu, Hawaii 96809
(808) 548-7635

Office of the Governor

Richard L. O'Connell, Director
Office of Environmental Quality Control
550 Halekauwila St, Room 301
Honolulu, Hawaii 96813
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CITY AND COUNTY GOVERNMENTS

HAWAII

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Planning Department
25 Aupuni Street
Hilo, Hawaii 96720
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(808) 961-8321

A. Duane Black
Department of Research and Development
25 Aupuni Street
Hilo, Hawaii 96720
(808) 961-8366

Al Nakaji
Department of Research and Development
25 Aupuni Street
Hilo, Hawaii 96720
(808) 961-8321

H. William Sewake, Manager
Department of Water Supply
25 Aupuni Street
Hilo, Hawaii 96720
(808) 935-1127

MAUI

Ralph Hayaski, Director
Department of Public Works
200 South High Street
Wailuku, Maui, Hawaii 96793
(808) 244-7846

Eric Soto, Director
Department of Water Supply
200 South High Street
Wailuku, Maui, Hawaii 96793
(808) 244-7834

HONOLULU

Tyrone Kusao, Director
Department of Land Utilization
650 South King Street, 7th Floor
Honolulu, Hawaii 96813
(808) 523-4256

George Moriguchi, Chief Planning Officer
Department of General Planning
650 South King Street
Honolulu, Hawaii 96813
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Chew Lun Lau
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UNIVERSITY OF HAWAII

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Prof. Ping Cheng
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Dr. Penelope Canan
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Doak Cox, Director
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APPENDIX D. AN ANNOTATED BIBLIOGRAPHY

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