Feasibility of a Geothermal Direct Use Enterprise Park in Puna, Hawaii

Andrea T. Gill
State of Hawaii
Department of Business, Economic Development and Tourism
Strategic Industries Division

Tyson Toyama, PE
Okahara & Associates, Inc.

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ABSTRACT

After a public information process which included surveying community members regarding the acceptability of 21 different geothermal direct use applications, four agriculture-related businesses were selected as candidates for a hypothetical 15-acre (6 ha) geothermal enterprise park in the Kapoho/Pohoki area of the island of Hawaii. The applications included greenhouse bottom heating, pasteurization of potting media, biodiesel production, and lumber drying. There was significant community support for the chosen applications, and minimal opposition expressed.

An engineering analysis concluded that a direct use enterprise park is technically feasible. Such a park could require up to 11 million Btu/hr (770 kcal/sec) of heat which might be supplied from a high-temperature resource, such as waste heat from a power plant, causing less than a 10° F (5.6° C) decrease in injectate temperature. The analysis was based on this hypothetical scenario, since waste heat is not currently available for direct use.

The direct use enterprise park would cost an estimated $12.5 million to develop and construct, and $738,000 per year to operate and maintain. The hypothetical park would only be marginally economically viable, even with significant financial subsidies. Annual revenues are expected to be $1.21 million, based on a $200/acre annual lease rate and a geothermal heat rate priced at $1.32/therm, or half of the prevailing average cost of diesel and propane. Annual revenues could be as high as $2.42 million if the geothermal heat was priced the same as conventional fuels.

The geothermal applications in the park could be expected to replace the use of 6,500-9,700 barrels of crude oil each year. In addition, 130 new jobs could be created.

INTRODUCTION

In 2005, the County of Hawaii, with assistance from the State of Hawaii and funding from the U.S. Department of Energy (USDOE), initiated a study (Okahara, 2007) of the feasibility of developing direct uses of geothermal heat in the Kapoho/Pohoiki region of Puna District, the eastern section of the island of Hawaii.

Puna is the location of the currently-erupting Kilauea Volcano as well as the state's only Known Geothermal Resource Area (KGRA), along the Kilauea East Rift Zone (KERZ). High-temperature, high-pressure resources in the Kapoho/Pohoiki area of the KERZ have been tapped by Puna Geothermal Venture (PGV), the only geothermal power plant in Hawaii, which is rated at 30 MW.

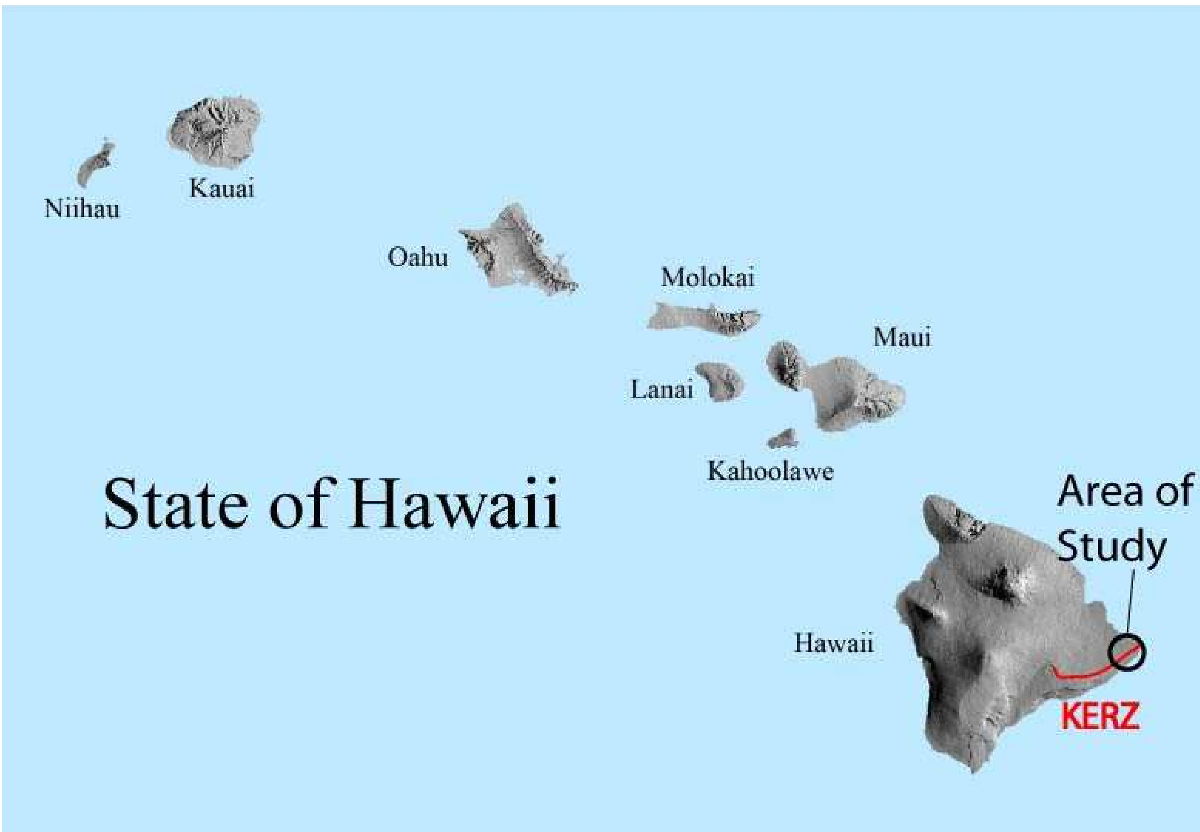

Figure 1. Feasibility study location.

The feasibility study's objectives included the following:

1. Identify geothermal direct use enterprises that are likely to be commercially viable as well as acceptable to the Puna community.
2. Identify possible geothermal resources in Kapoho that could be utilized for geothermal direct use.
3. Estimate capital and operational costs.
4. Estimate viable unit costs for heat.
5. Identify positive and negative impacts on the community of a geothermal direct use enterprise park.

The heat sources considered were the low-temperature, shallow, unpressurized aquifer within the KERZ, new wells to both shallow and deep resources, and PGV's waste fluid of 4,000 gpm (0.25 m^3/sec), currently injected at approximately 333° F (167° C). All sources were determined to be unfeasible at this time, as discussed below.

A number of direct use enterprises were identified as likely to be commercially viable and appeared to be acceptable to the community. An "enterprise park" consisting of these businesses was determined to be marginally economically feasible, even assuming significant financial subsidies.

The enterprise park is definitely technically feasible and would require between 6.6 and 11 million Btu/hr (462-770 kcal/sec) of geothermal energy if built as envisioned in the study. However, because of the current lack of an economic heat resource, it is unlikely that such an enterprise park will be developed in the near future.

BACKGROUND

Like many other parts of the world, Hawaii has a long history of cultural, therapeutic, recreational and casual use of naturally-occurring warm springs and steam vents. However, unlike many other parts of the world, these informal uses have not led to direct use development for commercial purposes, for instance those supporting agricultural endeavors.

In the late 1980s, the State of Hawaii and the University of Hawaii, with USDOE funds, sponsored a small-grants program supporting entrepreneurs who wished to use waste heat from the experimental HGP-A geothermal well (Beck, 1989). These small demonstrations engendered much enthusiasm, but the program was ended when the HGP-A well was permanently sealed in 1989. The HGP-A well had been drilled in 1976 to demonstrate Hawaii's high-temperature resource, and had provided steam to a pilot 3-MW power plant intended to encourage commercial geothermal development. After private sector interest was attracted, the HGP-A power plant equipment was sold and the well was shut in.

The small demonstrations of the Community Geothermal Technology Program focused on agricultural and artistic uses of geothermal heat, steam, and silica. Some of the projects involved applications which were considered by the current feasibility study, including greenhouse bottom heating, food dehydration, and pasteurization of potting media.

POTENTIAL RESOURCES

Both high-temperature and low-temperature geothermal resources occur in Puna. However, the feasibility study concluded that none of the existing resources—shallow wells and waste heat from PGV—are both sufficient and available for direct use. In addition, new wells, whether shallow or deep, appear to be prohibitively expensive. Puna's geothermal resources are described more fully in previous papers (Gill, 2004 and Gill, 2005) and in the feasibility study (Okahara, 2007).

Shallow, low-temperature resources

Heated, slightly saline water occurs in a thin layer at the top of the aquifer within KERZ, where it has been penetrated by a number of shallow wells drilled to explore for potable water or for geothermal energy. This water is not under any significant pressure and flows underground generally from the rift zone east and northeast toward the coast, where it may emerge in warm ponds and springs. Although the temperature of these shallow waters ranges approximately from 100-200° F (38-93° C) in existing monitoring wells within the KERZ, the hot water production capacity of each well is uncertain and is suspected to be low.

Dr. Stephen B. Gingerich attempted to locate and quantify shallow geothermal resources supplying hot water to several of the monitoring wells considered in the feasibility study as well as other shallow wells in the vicinity (Gingerich, 1995). Dr. Gingerich's research suggests that the sources of heated water in shallow wells are geological fractures that allow geothermally heated water to rise to the top of the water table. All shallow wells with heated water have a stratified temperature profile depicting a relatively thin layer of hot water sitting on cool water. Three shallow wells studied by Dr. Gingerich appeared to be down gradient of fractures producing the equivalent of 0.126 kg/s/m – 0.025 kg/s/m (0.61 gpm/ft – 0.12 gpm/ft) of 93° C (200° F) water.

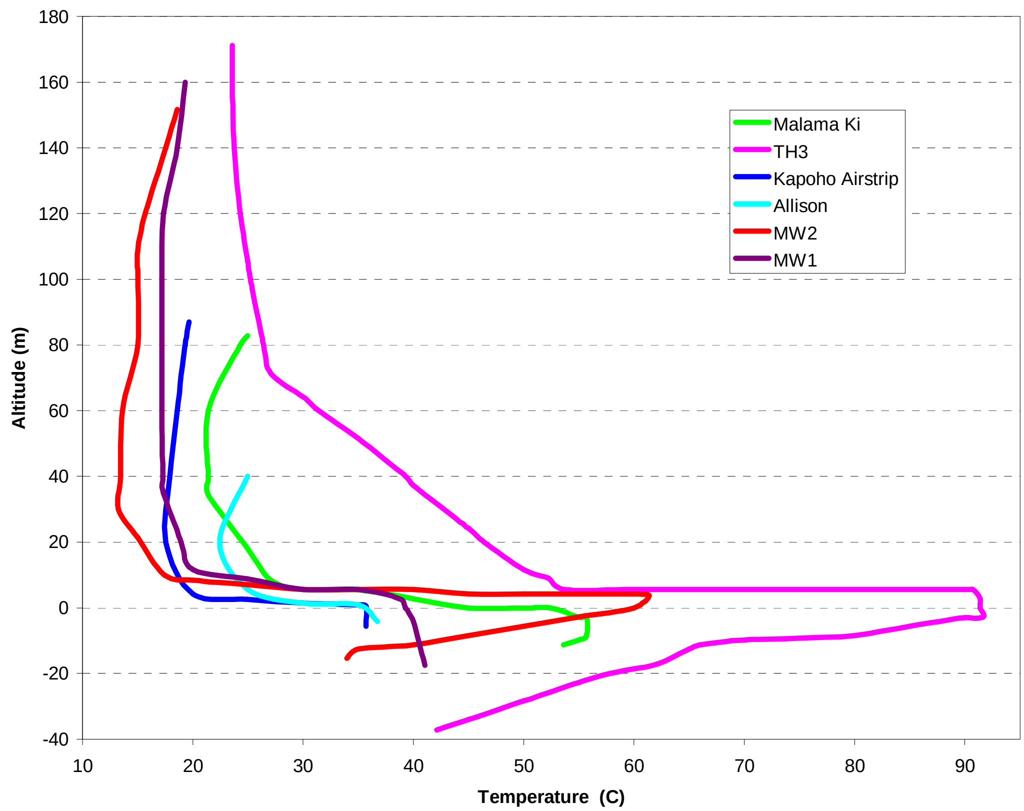

Figure 2. Temperature profiles in six KERZ shallow wells, 6/1/94 (Gingerich, 1995)

The accuracy of the modeling results and subsequent conclusions are unknown due to limited available computer resources, limited available data, and modeling limitations. The model created for Dr. Gingerich's dissertation was two-dimensional, though it was attempting to describe a three-dimensional system. It is unknown whether the sources of shallow geothermally-heated water are indeed fractures, and, if so, what their length is, how long they are expected to last, and the temperature and quantity of the water they emit. Nevertheless, the analysis was sufficiently discouraging to conclude that the shallow geothermal resource is probably inadequate to support commercial direct use operations.

Recognizing that this conclusion is based in great part on theoretical models, the State of Hawaii and the Geo-Heat Center, with USDOE support, are planning to test a downhole heat exchanger in one or two of the existing shallow monitoring wells. The resulting data may support the feasibility study's conclusion that insufficient heat is available, or it may demonstrate sustainable levels of heat extraction for certain low-temperature enterprises. The work is expected to be performed in mid-2007. Downhole heat exchangers have the advantage of requiring less power to extract heat: only circulating pumps are needed, and sometimes circulation can be established using natural convection. Also, no geothermal fluids are brought to the surface, eliminating the need for and expense of injection wells. Some heat is, of course, lost across the heat exchanger.

It is also possible to drill new wells to support a direct use enterprise park; the expense of this option, however, caused it to be eliminated from consideration. Drilling costs in Hawaii appear to be significantly higher than those experienced on the mainland U.S.; approximately $400,000 was quoted for a shallow, 8-inch (20.3 cm) diameter well which is 700 feet (213.4 m) deep. Furthermore, it was concluded that a new shallow well, tapping the unpressurized hot water at the top of Puna's aquifer, would be unlikely to reach any sources of heat greater than those already available to existing wells, which are deemed to be insufficient to support commercial direct use.

High-temperature resources

Waste heat from PGV's power plant was also considered as a potential resource for direct use. PGV currently injects approximately 4,000 gpm (0.25 m^3/sec) of fluid between 300-400° F (149-204° C) after electricity production. However, as the feasibility study progressed, PGV's plans to tap much of the waste heat using a new 8-MW bottoming cycle resulted in concern over the potential for direct use operations to negatively impact their electricity production and injection processes. The additional power generation is expected to reduce the temperature of the injectate to 168° F (75° C). A further temperature drop due to extracting heat for direct use could significantly increase the potential for scaling, possibly damaging pipes, heat exchangers, and injection wells. Thus, this potential resource was eliminated from consideration in the study.

New deep wells could tap the high-temperature, high-pressure resources suitable for electricity production but could cost $6-8 million each. Two to three wells would be needed to provide for both production and injection. In addition, the sale of electricity would have a higher rate of return than the sale of heat, so a high-temperature well is more likely to be drilled to support additional electricity generation than a direct use park.

For the purposes of this feasibility study, it was assumed that a high-temperature resource would be available from a hypothetical future operation, perhaps a power plant or an industrial facility such as an ethanol plant. It was assumed that fluid temperatures would be similar to those currently experienced at the 30-MW PGV power plant. It should be emphasized that this situation is truly hypothetical; no geothermal company other than PGV has plans to develop the KERZ resource, and no ethanol (or other large industrial) operation has been proposed for the Puna District.

POTENTIAL APPLICATIONS

A list of 21 potential direct use applications was developed by researching past, present and proposed uses of geothermal heat, identifying the ones which had potential for development in Puna (and excluding those, such as space heating and snow melting, which were inappropriate for the location). Once a list of potential applications was compiled, feedback was solicited from residents of Puna in order to determine which enterprises might be acceptable to the community. Each enterprise which appeared to be acceptable was briefly evaluated to determine which could be viable in terms of sustainability, potential to produce income, and support of existing Hawaii industries.

The County of Hawaii Geothermal Direct Use Working Group, a volunteer committee consisting of community members, Hawaiian educators and people having expertise in some aspect of geothermal technology, assisted in the development of this list. Feedback from the broader community was solicited at public meetings and through the distribution of a survey form. Meetings were sparsely attended by the general public but strongly attended by agriculturalists. The surveys were distributed through the Working Group, community organizations, the County's ongoing community planning process, at the 2006 University of Hawaii at Hilo Earth Day Fair, and by other means. A total of 92 survey responses were received.

Survey respondents were categorized by whether they lived in the Pahoa area, nearest to the geothermal development, or elsewhere on the island. Of the 92 respondents, 24 (26%) were from Pahoa. Pahoa residents seemed to strongly endorse agriculture-related applications, with less support for industrial or vanity/hygiene enterprises.

Overwhelmingly, geothermal direct use enterprises were supported by survey respondents. Approval ratings ranged from a low of 61% approval for one application (ethanol distillation) to a high of 90% approval (for fruit and vegetable drying.) Disapproval ratings ranged from a low of 0% disapproval (for seed drying) to a high of 10% disapproval of spas/onsen and Rumber® production.

Based on this process, four geothermal direct use enterprises were retained for consideration. These were greenhouse bottom heating, pasteurization of potting media, biodiesel production, and lumber kilns. The heat requirements for these four applications are summarized in the following table. Equivalent barrels of crude oil are based on an energy content of 5.8 million Btu/bbl and a water heating efficiency of 63%.

GEOTHERMAL DIRECT USE	UNIT	HEAT DEMAND (Btu/hr) PER UNIT	EQUIV. BBL OF OIL/UNIT
Greenhouse Bottom Heating	Acre/year	5.9×10^5 Average 1.1×10^6 Maximum	1.4×10^3
Pasteurization of Potting Media	1,000 pounds		
(First 10 min.)		1.4×10^5	3.8×10^{-2}
(After 10 min.)		8.6×10^1	2.4×10^{-5}
Biodiesel Production	10,000 gallons per year	4.4×10^4	1.1×10^2
Lumber Kiln (Average Heat Demand)	200,000 Board Feet per year (appx. 10% of est. sustainable local production capacity)	3.0×10^4	72
(Initial Heat Demand, First 24 Hours)		8.6×10^5	5.6

Table 1. Estimated geothermal direct use heat requirements

In addition, nine enterprises were identified as having high community appeal, but they offer limited income-producing potential and/or are small consumers of heat. These applications included fruit drying, seed drying, food processing, papaya disinfection, community commercial kitchen, fish drying, laundromat, university research center, and hot water treatment for coqui frog eradication. These nine applications may have potential for small-scale development.

Other applications reviewed by the community but determined to be non-viable, or unlikely to be viable for various reasons, included aquaculture, drying concrete blocks, ice plant/cold storage/refrigeration, Rumber® production (wood substitute from rubber tires), soap making, spa/onsen, and bathing. An ethanol distillation plant was removed from consideration because it would be an industrial application of geothermal energy on the same scale as a power plant, and should be studied independently. All of the other direct use applications consume small amounts of heat relative to ethanol distillation.

ENGINEERING ANALYSIS

A 15-acre direct use enterprise park utilizing high-temperature waste heat from an operation such as PGV is definitely technically feasible. The park described in the feasibility study, supporting a mix of primarily agricultural-related tenants, would have an estimated heat demand averaging 6.6 million Btu/hr (462 kcal/sec) and a peak heat rate demand of 11 million Btu/hr (770 kcal/sec). A high-temperature application such as a power plant could provide 20 million Btu/hr (1,400 kcal/sec) from 4,000 gpm (0.25 m^3/sec) of spent geothermal fluid and sustain a temperature drop as little as 10° F (5.6° C) in its injectate.

Twenty million Btu/hr can provide enough heat for 18 acres of greenhouse bottom heating at a peak heat consumption of 1.1×10^6 Btu/hr per acre, pasteurize over 140 tons of potting media per day at a heat consumption rate of 1.4×10^5 Btu/hr, produce approximately 4.5 million gallons of biodiesel per year at a heat consumption rate of 38,300 Btu/gal, dry more than 2 million board feet (BF) of lumber annually at a heat consumption rate of 3.0×10^4 Btu/hr per 200,000 BF, or provide for a combination of these enterprises.

This heat extraction potential is based on PGV's geothermal fluid flow of 4,000 gpm according to the following equation:

$$q = \dot{m} c_p (\Delta T)$$

Where: q = heat flow rate (Btu/hr)

$\dot{m}$ = mass flow rate (lb/hr) = $\dot{Q}\rho$, where

$\dot{Q}$ = volumetric flow rate (gpm) and

ρ = density (lb/gal)

c_p = specific heat of water (Btu/lbm/°F)

ΔT = temperature fall (°F)

so that q = (4,000 gpm) (8.34 lbm/gallon) (1.0 Btu/lbm/°F) (1° F) (60 min/hr) = 2,001,600 Btu/hr.

Calculated heat extraction potential from a 4,000 gpm source is given in Table 2, below.

Δ T (°F)	**Heat Extracted (Btu/hr)**
1	2,001,600
2	4,003,200
3	6,004,800
4	8,006,400
5	10,008,000
6	12,009,600
7	14,011,200
8	16,012,800
9	18,014,400
10	20,016,000
11	22,017,600
12	24,019,200
13	26,020,800
14	28,022,400
15	30,024,000
16	32,025,600
17	34,027,200
18	36,028,800
19	38,030,400
20	40,032,000

Table 2. Heat extraction potential from 4,000 gpm geothermal fluid flow rate

The feasibility study proposed a direct use system based on three fluid loops in order to be robust and flexible, responding to dynamic changes where the heat source temperatures may change gradually and heat consumption rates may change rapidly. The system would need to be modular and have provisions for expansion without sacrificing operational efficiency. It must reliably satisfy heat demands with dependable constant temperatures.

The first fluid loop, the geothermal fluid loop, would be the heat source, supplying heat through a heat exchanger. If the heat was supplied by a power plant, it would be extracted after electricity production and before injection.

The second loop, the primary direct use fluid loop, would consist of the secondary fluid (presumed to be potable water from the County system), a hot water storage tank, pumps, piping and a heat exchanger. Variable speed pumps would circulate cold secondary fluid from the storage tank to the heat exchanger and, after heating, back to the storage tank.

The third fluid loop is the secondary direct use fluid loop. Pumps would circulate the hot secondary fluid from the storage tank to the direct use enterprises, and then back to the storage tank for reheating. It was assumed that temperatures of 180-200° F (82-93° C) would be available to the direct use applications.

In terms of replacing fossil fuels, 6.6 million Btu/hr of geothermal heat could supplant 1.8 bbl of crude oil each hour, or 15,800 bbl of crude oil annually.

HYPOTHETICAL ENTERPRISE PARK

A hypothetical geothermal direct use enterprise park featuring a mix of tenants based on the analysis described in “Potential Applications,” above, could utilize 15 acres (6 ha) of agriculturally zoned land in the Kapoho/Pohoiki area. The source of heat is presumed to be waste heat from a high-temperature application such as a power plant.

“Economic feasibility” was examined using two extreme definitions. At one extreme, “economic feasibility” meant the ability to deliver heat at a reasonable rate for customers, provide an attractive rate of return for investors, and generate sufficient income to indefinitely sustain system operations.

At the other extreme, it was assumed that capital costs for the park would be subsidized, possibly by a government entity, and that a return on investment was not a priority. In this case, “economic feasibility” for the subsidized park was defined as the ability to deliver heat at a reasonable rate to geothermal direct use customers while maintaining the ability to indefinitely sustain system operations. The geothermal enterprise park would only need to generate enough revenue to pay for operations and maintenance. An estimated $9.2 million in financial subsidies would pay for capital costs. This was selected as the base scenario for the economic analysis.

The enterprise park would only be marginally economically feasible even if significantly subsidized. Funding support on the order of $9.2 million is required to achieve a 7-year simple payback, whereas without the subsidy the anticipated simple payback is 26 years.

This payback was based on an assumed geothermal rate charge equivalent to half the cost of conventional energy sources which would generate sufficient income to cover O&M costs and be attractively low to tenants. If this rate were increased, the payback period would correspondingly decrease. For instance, if the geothermal heat rate charge was equivalent to the cost of conventional fuels, the total simple project payback period would drop from 26 years to 7.4 years.

The direct use enterprise park would cost an estimated $12.5 million to develop and construct, and $738,000 per year to operate and maintain. This O&M budget includes costs such as geothermal system management fees, maintenance and preventative maintenance, on-site operator's wages and benefits, insurance, lease fees, property tax, and pump electricity; some of the costs are, of necessity, estimates. Annual revenues are expected to be $1.21 million, based on a $200/acre annual lease rate and a geothermal heat rate priced at $1.32/therm, or half of the prevailing average cost of diesel and propane. If the businesses paid the same price for geothermal heat as is currently paid for conventional fuels, annual revenues would be $2.43 million.

The economic impact of such a park depends on the investment in each enterprise. Assuming an equal investment of $500,000 in each of five enterprises—the four applications highlighted above (greenhouse bottom heating, potting media pasteurization, biodiesel and lumber kiln) plus a university research operation—the park can be expected to generate $9.2 million in additional sales, 130 new jobs, and $380,000 in additional taxes. Note that the park was also assumed to include a community center with a certified kitchen, but that this activity was not expected to generate revenue.

At this level of investment, the geothermal applications in the park can be expected to replace the use of 6,500-9,700 barrels of crude oil each year. For every $1,000 of electricity expenditures that can be replaced by geothermal resources, 9.3 barrels of crude oil can be supplanted and the release of 4 tons of CO_2 can be avoided. Every $1,000 which is not spent on diesel means that 6.86 barrels of crude oil won't be consumed and 2.94 tons of CO_2 will not be released.

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The full text of the feasibility study is available online at www.hawaii.gov/dbedt/info/energy/renewable/geothermal.

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