Geothermal Resource and Economic Assessment for the Production of Hydrogen Energy in Hawaii

Submitted by:
State of Hawaii
Department of Business, Economic Development and Tourism

In Conjunction With:

Sentech, Inc,
Bethesda, MD

GeothermEx
Richmond, CA

Application for Federal Assistance (SF 424)

Federal Assistance Budget Information (DOE F 4600.4)

Technical Summary

Background

With no indigenous fossil fuels, over 90% of Hawaii's energy is derived from imported crude oil and finished petroleum products. This reliance on imports drives up the price for electricity in the islands and makes Hawaii particularly vulnerable to volatility in the price of petroleum and potential interruptions in delivery of fossil fuels. At the same time, Hawaii is blessed with extraordinary potential to produce renewable energy, particularly geothermal energy. While renewable energy can help alleviate Hawaii's dependence on fossil fuel imports for generating electricity, it can do little to reduce Hawaii's dependence on fossil fuel for transportation. Hydrogen provides a potential avenue to expand the reach of renewable energy, allowing it to address Hawaii's energy requirements for transportation. Given the potential surplus of geothermal resources available on Hawaii, generating hydrogen using geothermal energy may offer a means to establish Hawaii as a model for the future hydrogen energy economy.

Purpose and Objectives:

The overall objective of this study is to assess the potential available geothermal resources on the Big Island of Hawaii and ascertain how a hydrogen energy infrastructure could be developed using that resource. The project will evaluate the potential to marry geothermal resources to hydrogen generation technologies in order develop a hydrogen energy infrastructure on the Big Island of Hawaii. By assessing the potential for hydrogen generation, this project will assess potential new markets for geothermal energy on the island of Hawaii and will demonstrate the technical and financial feasibility of developing a hydrogen infrastructure in this island environment.

Approach

This project will assess the potential to use geothermal energy as the primary energy source to develop a hydrogen energy economy on the Big Island of Hawaii. Our approach will combine an inventory of the geothermal resources on the island with an analysis of potential avenues for manufacturing and storing hydrogen. Additionally, we will develop an outline of the financial and policy paths that could be followed to develop a hydrogen infrastructure on Hawaii. While this additional work is beyond the original scope of work requested within the SEP RFP, we believe that assessing such a path is a critical step to Hawaii in evaluating State investment of hydrogen infrastructure to move from theory to practice. It is consistent with DOE's implementation of the President's Hydrogen Fuel Initiative and the stimulus for Hawaii's willingness to cost-share this study. Our assessment will be divided into three phases.

- In *Task One*, our team will evaluate and characterize the geothermal resource potential on the Big Island of Hawaii;
- In *Task Two*, based on the results of Task One, our team will conduct a thorough technical and economic analysis of the potential for making and storing hydrogen using the identified geothermal resources;
- In *Task Three,* our team will develop an estimate of the potential investment required to develop a geothermal hydrogen infrastructure on Hawaii and identify feasible approaches to developing that infrastructure.

Results/Benefits

The result of this project will be a comprehensive assessment of the potential to develop a geothermal energy-based hydrogen infrastructure on the Big Island of Hawaii. This assessment will categorize the technical feasibility, potential cost, and the policy issues that will needed for such a project concept to be realized. The methodology used in this assessment will be available for use in other assessments of the potential to generate hydrogen from geothermal energy, and the assessment will also have the potential to serve as a springboard to the actual development of a geothermal energy-based hydrogen infrastructure in Hawaii.

Technical Narrative
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Background

As a state, Hawaii's energy situation is unique. With no indigenous fossil fuels, over 90% of Hawaii's energy is derived from crude oil and finished petroleum products imported from Alaska or foreign countries. This reliance on imports drives up the price for electricity in the islands and makes Hawaii particularly vulnerable to volatility in the price of petroleum and potential interruptions in delivery of fossil fuels.

At the same time, Hawaii is blessed with extraordinary potential to produce renewable energy. Wind, solar and geothermal resources are all plentiful in the state. Although most of the state's islands produce some form of renewable energy, the Big Island of Hawaii has been the forerunner in developing renewable resources. In 2000, 29.1% of the Big Island's electricity resources came from renewable sources, including 23.2% from geothermal energy, 4.0% from hydropower and 1.9% from wind power. Even with this level of renewable consumption on the island, there is still potential to develop additional renewable energy resources, especially geothermal resources.

To date, six geothermal resource areas capable of supporting electrical power generation have been identified in Hawaii: (1) Kilauea Rift Zone, (2) Mauna Loa Southwest Rift Zone, (3) Mauna Loa Northeast Rift Zone, (4) Hualalai, (5) Haleakala East Rift Zone, and (6) Haleakala Southwest Rift Zone. Two of these areas are on Maui (Haleakala East and Southwest Rift Zones); the remainder are on the Big Island. The Kilauea Rift Zone on the Big Island is by far the largest known geothermal resource area in the U.S., if not the world. The Kilauea Rift Zone is subdivided into an East Rift Zone and a Southwest Rift Zone. The Kilauea East Rift Zone (KERZ) is the most well-defined of the geothermal zones in Hawaii, and a 30 MW geothermal power plant has been in commercial operation there since April 1993.

The wells drilled within the KERZ area have demonstrated very high resource temperatures, reaching nearly 700°F in some wells. The wells supplying the existing power plant have demonstrated generation capacities of 20 to 30 MW each. These high temperatures and prolific well productivity make the KERZ area one of the most attractive geothermal resource areas in the U.S. The electrical power capacity per square mile potentially available within the KERZ has been estimated as between 20 and 70 MW. Given that the KERZ is on the order of 250 square miles in extent, it is likely that geothermal energy reserves for several thousand megawatts of potential power capacity lie within the KERZ area alone.

While renewable energy sources can help alleviate Hawaii's dependence on fossil fuel imports for generating electricity, there are several areas in which renewables suffer in comparison to fossil fuels. Unlike fossil fuel-fired power plants, the variability associated with some intermittent renewable resources, like wind and solar power, makes it difficult for a utility to "dispatch" or schedule electricity generated from those renewable resources. Additionally, to date, no method has been found to use Hawaii's renewable resources to reduce Hawaii's dependence on imported fossil fuel for its transportation energy needs.

Hydrogen provides a potential avenue to expand the reach of renewable energy, allowing it to address Hawaii's energy requirements for transportation and allowing the scheduling of electricity generated by intermittent renewable resources. The generation of hydrogen from renewable resources for use as an energy storage medium and as a fuel for transportation applications has great potential to alleviate a large part of Hawaii's electricity and energy problems while reducing environmental impacts. Given the vast surplus of geothermal resources available on the Big Island, generating hydrogen using geothermal energy may offer a means to establish Hawaii as a model for the hydrogen energy.

For some time, the State of Hawaii has recognized that investment in a hydrogen infrastructure can reduce its oil dependence, diversify the energy economy, and increase the use of indigenous renewable resources.

Hydrogen also has the potential to diversify the Hawaiian economy with associated high technology business. In 2000, the State commissioned a hydrogen and fuel cell feasibility study to analyze and recommend options that could result in hydrogen becoming a future ingredient in Hawaii's energy economy. Specifically, the study analyzed the costs and benefits of incorporating large-scale hydrogen use into the State's energy economy; assessed the feasibility of incorporating new and existing technologies for hydrogen use and infrastructure; developed a strategy to incorporate hydrogen into Hawaii's energy economy; and defined specific next steps or actions to implement a hydrogen strategy.

The feasibility study concluded that hydrogen would be able to compete with gasoline in Hawaii as a transportation fuel by 2010, assuming that a fuel cell automobile is available, as both the U.S. DOE and the major auto manufacturers have projected in the U.S. Government's "Freedom Car" Initiative. The Big Island of Hawaii in particular was identified as an opportunity to evaluate and implement integrated hydrogen energy infrastructure projects owing to its unique location, resources, and energy issues. Some of these unique features include:

- Availability of extensive renewable energy resources, including geothermal energy, which already produces up to 30 MW of electricity for the Big Island;
- Establishment of a distributed generation test and evaluation center at the Natural Energy Laboratory of Hawaii (projected to be commissioned in 2003/2004);
- High energy costs, with gasoline exceeding $2.20/gallon and retail electricity costs exceeding $0.21/kWh;
- International airport and power plant site adjacent to the Natural Energy Laboratory that are being considered for development of hydrogen production and infrastructure;
- Consideration by the leadership of the Hawaii State Legislature to evaluate the concept of a Hydrogen Energy Authority.

Geothermal energy has been identified as the best option for producing large quantities of hydrogen in Hawaii for energy applications because:

- Hydrogen can be generated using geothermal energy, which has the following favorable attributes: (a) it is an indigenous resource in Hawaii, (b) it is renewable, (c) it is emission-free (the small amount of hydrogen sulfide and carbon dioxide produced being injected back), and (d) it has the highest availability and capacity factors compared to any other source of renewable power.
- Readily available off-peak, and therefore cheaper, power from geothermal power plants can be utilized for hydrogen generation at a lower cost.
- Hydrogen production will allow utilization of the vastly higher power capacity potentially available from geothermal resources than the relatively limited present or future power market on the Big Island could absorb.
- Geothermal-derived hydrogen from the Big Island can be exported to other islands where geothermal resources do not exist – providing renewable energy to the entire State. This is likely to be lower cost than the abandoned concepts of sub-sea cables for exporting geothermal power throughout Hawaii.
- The exceptionally high temperature of the geothermal resources on the Big Island (up to magmatic temperatures) can allow innovative uses of thermal energy, such as high-pressure steam electrolysis, to substitute a significant part of the electricity needed for hydrogen production. This can reduce the cost of hydrogen production substantially.

Project Objective

The overall objective of this study is to assess the potential available geothermal resources on the Big Island of Hawaii and ascertain how a hydrogen energy infrastructure could be developed using that geothermal resource. The project will evaluate the potential to integrate geothermal resources to hydrogen generation technologies in order develop a hydrogen energy infrastructure on the Big Island of Hawaii.

In order to reach this objective, a thorough resource analysis of the geothermal potential of Hawaii will be conducted. Based on this inventory of geothermal resources, an engineering and financial analysis will be conducted to determine the costs of energy and hydrogen that could be produced from geothermal resources. Additionally, an analysis will be conducted to estimate the investment that would be required to develop a hydrogen infrastructure and identify potential funding sources (both the state as well as private sector).

The analysis will be directed by the State of Hawaii and conducted by two consulting companies, GeothermEx and Sentech, who have been assisting the State in geothermal and hydrogen characterizations, respectively, for a number of years. The familiarity of these two team members with the current state of the Hawaiian energy economy, and the recent related analyses they have conducted in Hawaii, will help to facilitate the rapid completion of this project.

Technical Approach

This project will assess the potential to use geothermal energy to develop a hydrogen economy on the Big Island of Hawaii. Our approach will combine an inventory of the geothermal resources on the island with an analysis of potential avenues for manufacturing and storing hydrogen. Additionally, we will develop an outline of the financial path that could be followed to develop a hydrogen infrastructure on Hawaii. While this additional work is beyond the original scope of work requested within the SEP request for proposal, we believe that identifying such a path is a vital step in assessing the State's interest in realizing a hydrogen energy infrastructure.

Our assessment will be divided into three phases.

- In *Task One*, our team will evaluate and characterize the geothermal resource potential on the Big Island of Hawaii. Analysis will be conducted to determine the potential value of electricity and district heating generated from geothermal resources, as well as to identify other potential markets for Hawaii's geothermal resources.
- In *Task Two*, based on the results of Task One, our team will conduct a thorough technical and economic analysis of the potential for making and storing hydrogen using geothermal resources.
- In *Task Three,* our team will expand on the results of the first two phases by developing an estimate of the potential investment required to develop a geothermal hydrogen infrastructure on Hawaii.

Task One: Updating of Geothermal Resources

Geothermal resources are already an important source of energy on the Big Island of Hawaii. In 2000, 23.2% of the Big Island's electricity was generated from geothermal resources. Given the difficulty in siting new conventional power plants on Hawaii due to aesthetic and environmental reasons, continual development of Hawaii's geothermal resources will be crucial to meeting the demand growth expected in the near future as the Big Island's tourist economy continues to expand.

This task will be divided into two subtasks:

- **Subtask 1a:** Assess the available exploration, drilling, and well testing data to estimate the megawatt capacity potentially available from the various resource areas in Hawaii. This assessment will be a probabilistic analysis based on the consideration of the uncertainties in the various resource parameters. The main product of this task will be histograms and cumulative probability distributions of megawatt capacities available within each known geothermal zone.

For each geothermal zone the minimum and most-likely geothermal reserves will be defined from these results.

- **Subtask 1b:** Assess available well and reservoir performance data, as well as drilling and operations costs from the KERZ, to estimate the capital cost ($ per installed kilowatt) and operations and maintenance cost (¢ per kilowatt-hour) of geothermal power in the KERZ. For the estimation of the overall capital cost, the analysis will consider well productivities, drilling costs, costs of the gathering and injection systems and power plant cost. For estimating the operations and maintenance cost, the analysis will consider the costs of the following routine well maintenance and workover, make-up well drilling, power plant, gathering system and injection system. Comparing the results of the cost analysis for the KERZ, the capital as well as operations and maintenance costs for the other geothermal zones will be approximated.

Our inventory of geothermal resources will also include:

- Evaluating the potential for power generation (including current and future available geothermal conversion technologies), including a calculation of the upper limit and average predicted level of electricity production from geothermal resources through 2025;
- Evaluating the potential for district heating using geothermal resources;
- Evaluating the potential for other direct-use development using geothermal resources;
- Calculating the potential electricity to be generated given maximum and likely geothermal resource development through 2025;
- Estimating wholesale cost of electricity through 2025 (with confidence intervals);
- Predict off-peak availability of electricity through 2025.

Our output for this task will include an updated inventory of the Big Island's geothermal resources, as well as calculations of the potential use of these resources for power generation, district heating or other commercial enterprises with current and future projected technologies. In order to better communicate these results to the public, the results of this task will be made available to the public through this report and a posting of the results on the DBEDT website.

Subtask	Start Date	End Date	Deliverable	Due Date
Assess the available exploration, drilling, and well testing data to estimate the megawatt capacity potentially available from the various resource areas in Hawaii.	Immediately upon award of contract	Four months after contract award	Report showing histograms and cumulative probability distributions of megawatt capacities available within each known geothermal zone	Four months after contract award
Assess available well and reservoir performance data, as well as drilling and operations costs from the KERZ, to estimate capital cost and operations and maintenance cost (¢ per kilowatt-hour) of geothermal power in the KERZ.	Immediately aftger completion of above subtask	Two months after completion of above subtask	Report showing results of assessment including capital and O&M costs for geothermal energy in the KERZ.	Six months after contract award

Task Two: Calculation of Potential Hydrogen Resource

Based on the inventory of potential geothermal resources conducted in Task 1, Task 2 will focus on evaluating potential methods for manufacturing and storing hydrogen and calculating the potential volume of hydrogen that could be produced from geothermal resources on Hawaii. Our analysis will take into account a variety of hydrogen generation and storage technologies, and will analyze those technologies from both technical feasibility and cost perspectives.

Our analysis will build on Sentech's study for DBEDT and the Hawaii Natural Energy Institute, which developed an analysis of potential pathways toward the development of a hydrogen infrastructure in Hawaii. This analysis examined a variety of pathways to generating hydrogen from both fossil and renewable resources, including geothermal power. The results of this analysis demonstrated that the Big Island had some potential for the cost-effective development of hydrogen from geothermal resources. Our Task Two analysis will seek to validate that assumption by:

- Collecting information on the technical characteristics and costs of various hydrogen generation technologies, including electrolyzers and reformers. Information will be collected via publicly available documents and solicited from manufacturers;
- Estimating steam supply from geothermal resources for use in a high-pressure steam electrolysis process in the various resource zones;
- Assessing the capital, operating and maintenance costs of high-pressure steam supply. The cost analysis methodology will be similar to that proposed for Subtask 1b except that the capital cost will be represented in terms of $ per million Btu/hour and the operations and maintenance cost as cents per million Btu generated;
- Collecting information on the technical characteristics and costs of various hydrogen storage technologies. Information will be collected via publicly available documents and solicited from manufacturers;
- Calculating the cost of hydrogen generated and stored from geothermal resources by conducting life-cycle cost analyses;
- Analyzing various combinations of hydrogen generation and hydrogen storage technologies to determine the cost to produce and store hydrogen at 5, 10, 15 and 20 years;
- Calculate the potential price of hydrogen as a fuel at 5, 10, 15, and 20 years and comparing the value of hydrogen generated from each scenario to other transportation fuels on a $/MMBTU basis.

The output from this task will be the development of an analytical tool to evaluate the potential value of different scenarios for generating and storing hydrogen generated using geothermal resources. A report detailing the results of our modeling exercise will also be prepared and presentations made to State energy officials responsible for implementing Hawaii's hydrogen program.

Subtask	Start Date	End Date	Deliverable	Due Date
Collect information on technical characteristics / costs of hydrogen generation / storage technologies	Immediately after completion of Task 1	Two months after completion of Task 1	Report detailing technical information collected on various hydrogen generation and storage technologies	Two months after completion of Task 1
Estimate steam supply and costs for use of high-pressure steam electrolysis in various resource zones.	Immediately after completion of Task 1	One month after completion of Task 1	None	--
Calculate cost of hydrogen generated and stored from geothermal resources by conducting life-cycle cost	Two months after completion of Task 1	Three months after completion	Report detailing results of scenario cost analysis of generation/storage scenarios and life cycle cost analysis.	Four months after completion

analyses		of Task 1		of Task 1
Conduct cost analysis of hydrogen generation/storage scenarios	Three months after completion of Task 1	Four months after completion of Task 1	Report detailing results of scenario cost analysis of generation/storage scenarios and life cycle cost analysis.	Four months after completion of Task 1

Task Three: Assessment of Hydrogen Infrastructure Financial and Policy Requirements

Tasks 1 and 2 focus on developing data and models in order to estimate the technical and economic potential for developing a geothermally-based hydrogen infrastructure on the Big Island of Hawaii. Task 3 will cover an equally important area: the financial and institutional barriers to the development of a hydrogen energy infrastructure.

Development of a hydrogen infrastructure in any state will involve significant financial and regulatory backing from all levels of government, as well as from the private sector. Analyzing and quantifying the cost and potential funding sources for a hydrogen energy infrastructure is an important step in bringing such an infrastructure from proposal to reality. Task 3 will seek to identify the cost of developing a hydrogen infrastructure on Hawaii, evaluate the potential government funding sources that could be used to support the development of a hydrogen infrastructure on the Big Island, and quantify the potential return on investment from the development of such an infrastructure. Our work under this task will include:

- Assessing the historical level of commitment of State and Federal resources towards renewable energy in Hawaii;
- Analyzing relevant state laws and regulations to assess where change may have to take place in order to facilitate hydrogen economy;
- Assessing potential avenues within the state for implementing and financing a Hawaii "Hydrogen Authority";
- Determining the level of financial commitment required to sustain a Hawaii "Hydrogen Authority;
- Identifying potential sources of leverage government funding for hydrogen, including Federal funds, international, and private sector funding;
- Identifying potential types of funding vehicles, including grants, tax credits, tax subsidies, loans, cost-sharing, and other approaches;
- Calculatnig the potential cost of a full hydrogen energy infrastructure on Hawaii and the potential return on investment (ROI) for government funding of such a project.

The output for this task will be the development of a financial roadmap for funding the development of a hydrogen energy infrastructure. Included will be a financial analysis of the most cost-effective funding sources and a calculation of the potential economic growth that could result from investment by Hawaii in a Hawaii Hydrogen Energy Authority. A report detailing the results of our modeling exercise will also be prepared and presentations made to State energy officials responsible for implementing Hawaii's hydrogen program.

Subtask	**Start Date**	**End Date**	**Deliverable**	**Due Date**
Assess historical level of commitment of government resources towards renewable energy in Hawaii	Immediately after completion of Task 1	Two months after completion of Task 1	Report detailing analysis of potential financial commitment and ROI necessary to support "Hydrogen Authority" and hydrogen infrastructure on	Eight months after completion of Task 1

			Hawaii.	
Analyze state laws and regulations relevant to a hydrogen infrastructure	Immediately after completion of Task 1	Two months after completion of Task 1	White paper detailing relevant state laws and regulations for a hydrogen infrastructure	Two months after completion of Task 1
Assess potential avenues within the state for implementing/ financing Hawaii "Hydrogen Authority";	Immediately after completion of Task 1	Three months after completion of Task 1	None	--
Perform analysis to determine level of financial commitment required to sustain a Hawaii "Hydrogen Authority	Two months after completion of Task 1	Five months after completion of Task 1	Report detailing analysis of potential financial commitment and ROI necessary to support "Hydrogen Authority" and hydrogen infrastructure on Hawaii.	Eight months after completion of Task 1
Identify potential sources of government funding and funding vehicles for hydrogen.	Three months after completion of Task 1	Five months after completion of Task 1	Report detailing analysis of potential financial commitment and ROI necessary to support "Hydrogen Authority" and hydrogen infrastructure on Hawaii.	Eight months after completion of Task 1
Calculate potential cost and return on investment of a full hydrogen infrastructure on Hawaii.	Five months after completion of Task 1	Eight months after completion of Task 1	Report and presentation detailing analysis of potential financial commitment and ROI necessary to support "Hydrogen Authority" and hydrogen infrastructure on Hawaii.	Eight months after completion of Task 1

Experience of Team Members
State of Hawaii Department of Business, Economic Development, and Tourism (DBEDT)

The Department of Business, Economic Development, and Tourism, through its Energy, Resources, and Technology Division (ERTD), plans and conducts a broad range of activities to meet the objectives of the state's energy program. The four key program objectives are:

- Dependable, efficient, and economical statewide energy systems capable of meeting the needs of the people;
- Increased energy self-sufficiency where the ratio of indigenous to imported energy use is increased;
- Greater energy security in the face of threats to Hawaii's energy supplies and systems; and
- Reduction, avoidance, or sequestration of greenhouse gas emissions from energy supply and use.

Consequently, State policy and program activities include support and promotion of research, development, demonstration, and use of renewable energy; energy-efficient practices and technologies;

development or expansion of appropriate energy systems; and mitigation of Hawaii's greenhouse gas emissions.

DBEDT is the department responsible for administering statewide energy programs for the State of Hawaii. They are responsible for the planning and execution of energy policy in three major areas: 1) statewide energy emergency preparedness; 2) energy conservation programs; 3) and development of renewable energy projects. In January 2003, the state appointed the DBEDT/ERTD Director as the State's Chief Technology Officer (CTO) to lead efforts to diversify the statewide economy, developing programs to increase investment in strategic technologies through public-private partnerships. A strategic technology economic development program for the State of Hawaii that focuses on Hawaii's outstanding competitive advantages in defense activity, natural resources, biotechnology, and ocean science and technology has been created.

GeothermEx

Since 1973, GeothermEx has provided consulting and operational services in the exploration, development, assessment and valuation of geothermal energy. GeothermEx is the largest company of its type in the Western Hemisphere, and has worked with major oil and mineral companies, electrical utilities, financial organizations, and governments to evaluate and/or develop geothermal resources in 44 countries. On behalf of government agencies, geothermal developers and project lenders, GeothermEx has been involved in geothermal developments in Hawaii since 1980. Work in Hawaii has included:

- geothermal lease evaluation;
- selecting sites and drilling targets for geothermal wells;
- geothermal well design and permitting;
- preparation of drilling bid documents and selection of drilling contractors;
- development, implementation and supervision of well workover / remediation plans;
- evaluation of drilling methods and costs;
- estimation of geothermal energy reserves;
- analysis of production / injection data from well tests and long-term field operations;
- numerical modeling to evaluate production / injection strategies;
- design, implementation and analysis of well tests in slim holes drilled for geothermal exploration in Hawaii;
- technical assistance in determination of pricing structures for geothermal steam and/or electricity;
- analysis of the effectiveness of geophysical and geochemical techniques in geothermal exploration in the unique Hawaiian environment;
- assessment of geothermal-related hazards;
- valuation of geothermal resources on specific Hawaiian properties;
- resource-related due diligence in support of project financing;
- evaluations of options for increasing geothermal power generation in Hawaii; and
- assessment of the potential for the development of hot spring resorts in Hawaii.

This work has been undertaken for a series of clients, notably Puna Geothermal Venture (PGV) and its lender Credit Suisse First Boston (CSFB), the Estate of James Campbell, Barnwell Industries, University of Hawaii, and DBEDT. The work undertaken by GeothermEx for PGV / CSFB and DBEDT is summarized below.

GeothermEx has been involved in nearly all aspects of the 30 MW geothermal project in Hawaii since its inception in 1990, including: monitoring of all project operations including drilling operations for three of the largest capacity geothermal wells in the world (between 20 and 30 MW each); evaluation of fluid production and injection trends; monitoring of geochemical and thermodynamic changes in the reservoir; periodic numerical simulation of the reservoir and assessment of new sites and targets for geothermal wells.

DBEDT's role vis-à-vis geothermal has been one of monitoring the existing geothermal power development (the PGV project), determining if and where additional geothermal potential exists in the state (for either power generation or direct use), and identifying potential hazards associated with geothermal development. From 1990 to the present, GeothermEx has assisted DBEDT with these tasks, as summarized in a series of annual reports on geothermal development at Puna, and in specific reports aimed at other areas of the state and other specific topics. Included in the latter category were evaluations of the utility of slim holes for geothermal resource exploration and evaluation, evaluation of volcanic, seismic and other hazards associated with geothermal development, identification of the most effective geothermal exploration methods in Hawaii, and investigations of the direct use of Hawaii's geothermal resources.

Sentech, Inc.
Sentech is an energy and environmental management consulting firm with significant expertise in hydrogen and renewable energy. Founded in 1989, Sentech specializes in technical, economic and market analysis, systems modeling, and communications and outreach activities. Sentech works with public and private sector clients including the Department of Energy, Environmental Protection Agency, national laboratories, energy companies and investment banks.

Since 2000, Sentech has been active in the hydrogen and clean energy fields within Hawaii. Our recent work in this area includes:

- For the Hawaii Natural Energy Institute, Sentech conducted an analysis of the feasibility of generating hydrogen through different pathways for use as an energy source. The analysis included full life-cycle costing of hydrogen from a variety of renewable resources, including geothermal, wind, and biomass power. This analysis has been used as the basis for further examination of the potential for a hydrogen energy economy in Hawaii, and has been a catalyst for increased interest in hydrogen in the state.
- Sentech is currently working with the Hawaii Electric Light Company on two concurrent projects to analyze the potential for DER microgrids and energy storage technologies to alleviate congestion on the Big Island's Kona Coast. This work involves a scenario analysis of various technology combinations and their impact on the performance of the grid, as well as an assessment of the potential to use energy storage to increase the penetration of renewables and distributed energy on Hawaii.
- Sentech is a partner in the team that is developing a hydrogen power park at the Natural Energy Laboratory of Hawaii Authority's Gateway Center on the Big Island. In this capacity, Sentech performs analytical and advisory work related to the development of this project.

Statement of Objectives/Cost Information

Statement of Objectives

Task 1:

Activity	RFP Technical Requirements
Assess available exploration, drilling, and well testing data to estimate the megawatt capacity potentially available from the various resource areas in Hawaii.	" projects that will involve updating the inventory of geothermal resources in a given state."
Assess available well and reservoir performance data, as well as drilling and operations costs from the KERZ to estimate the capital cost ($ per installed kilowatt) and operations and maintenance cost (¢ per kilowatt-hour) of geothermal power in the KERZ.	"evaluation of potential for power generation, district heating and other direct-use development"

Task 2:

Activity	RFP Technical Requirements
Collect information on technical characteristics / costs of hydrogen generation / storage technologies	"Inventories should include an evaluation of potential for...other direct-use development"
Estimate steam supply and costs for use of high-pressure steam electrolysis in various resource zones.	"Inventories should include an evaluation of potential for...other direct-use development"
Calculate cost of hydrogen generated and stored from geothermal resources by conducting life-cycle cost analyses	"Inventories should include an evaluation of potential for...other direct-use development" "incorporate detailed ...economic analyses models for specific sites"
Conduct cost analysis of hydrogen generation/storage scenarios	"Inventories should include an evaluation of potential for...other direct-use development" "incorporate detailed ...economic analyses models for specific sites"

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Task 3:

Activity	RFP Technical Requirements
Assess historical level of commitment of government resources towards renewable energy in Hawaii	
Analyze state laws and regulations relevant to a hydrogen infrastructure	
Assess potential avenues within the state for implementing/ financing Hawaii "Hydrogen Authority";	
Perform analysis to determine level of financial commitment required to sustain a Hawaii "Hydrogen Authority	
Identify potential sources of government funding and funding vehicles for hydrogen.	
Calculate potential cost and return on investment of	

a full hydrogen infrastructure on Hawaii.	

Evaluate cost of potential Federal and/or state subsidies to produce and distribute hydrogen **(Sentech Lead)**

- Perform ROI analysis to determine the feasibility of Big Island Hydrogen Authority

Cost Information

Task	Hawaii (DBEDT/ DLNR) Labor	Sentech Labor Hours	GeothermEx Labor Hours	TOTAL Labor Hours	Other Direct Costs (Travel)	TOTAL Cost
1: Geothermal Assessment		**80**	**320**	**400**	**$3,500**	
2: Hydrogen Assessment		**360**	**40**	**400**	**$5,000**	
3: Geothermal Hydrogen Feasibility		**360**	**80**	**440**	**$3,500**	
TOTALS	**$30,000**	**$68,000**	**$40,000**	**1240**	**$12,000**	**$150,000**

Cost Sharing:

The State of Hawaii is requesting $100,000 in funds from DOE and will contribute $30,000 in staff time and related in-kind services and $20,000 in cash to the conduct of the study. The total project cost will be $150,000 with a total cost-share of one-third (33%).

Personnel Resources

State of Hawaii Department of Business, Economic Development, and Tourism (DBEDT)

Priscilla Chin Thompson: Ms. Thompson will serve as the State of Hawaii's Principal Investigator for this project. Ms. Thompson serves as program manager for sustainable technology projects focusing on renewable energy and innovation within DBEDT. Current responsibilities include projects related to biomass energy, geothermal energy, distributed energy resources, and hydrogen/fuel cells. Her duties include interagency coordination for geothermal and biomass projects, coordination and conduct of meetings and workshops, performance of in-house analyses, cost and operational reviews, preparation and supervision of consultant contracts, and response to public information requests. Ms. Thompson has over 20 years of financial management and administrative experience in higher education, government, and industry.

Sentech

Jonathan Hurwitch: Mr. Hurwitch will serve as Project Manager and will oversee the completion of the project. He has served as principal investigator for all Hawaii hydrogen activities at Sentech. Mr. Hurwitch has worked with DOE's Energy Efficiency and Renewable Energy Programs for more than 25 years. He is an experienced scientist, market analyst, and project manager with more than twenty-five years of experience evaluating emerging power technologies including hydrogen, energy and renewable energy technologies.

Matthew Johnson: Mr. Johnson has significant experience in market and economic analysis of alternative energy technologies, including distributed energy and hydrogen and will serve as Task 3 leader. He is currently working on projects researching the impact of microgrids and energy storage for alleviating transmission congestion on the island of Hawaii, and has recently performed a competitive assessment of the market for hydrogen generation technologies. Mr. Johnson holds an MBA and has extensive experience in financial and regulatory analysis of electric generation technologies. He has developed a model to quantify the impact of regulation on the economics of distributed generation technologies, and designed a valuation model for use in valuing cogeneration power plants in emerging economies.

Kenneth Lee: Mr. Lee is currently working as a research engineer on projects related to distributed energy resources and thermal energy storage and will serve as task leader for Task 2. He is currently involved in a project with Hawaii Electric Light Company, performing a market and technology analysis of bulk energy storage systems and distributed generation technologies. He is also currently working on a project to assess the potential to generate hydrogen using distributed windpower. Mr. Lee is a mechanical/nuclear engineer with experience in the utility and energy industry. He is familiar with the design and analysis of utility and industrial power plants and systems. He has conducted numerous engineering analysis and evaluation of mechanical and electronic systems in power plants.

GeothermEx

Dr. Subir Sanyal: Dr. Sanyal has worked as a reservoir engineer since 1969 and will serve as Deputy Project Manager. His expertise includes project financing and management, economic analysis, property appraisals, reservoir engineering, numerical simulation, training of reservoir engineers, and software development. Since 1975, he has managed major geothermal projects in the United States, The Philippines, Japan, Costa Rica, Indonesia, Mexico, Nicaragua, Guatemala and Italy, and evaluated geothermal fields in two dozen countries around the world. Dr. Sanyal has also assisted clients in geothermal power sales and steam sales contract negotiations, property appraisals and market studies, and provided advice and due diligence for project financing in numerous countries. To date, this has enabled the generation of more than 6,000 MW of geothermal power, the total financed being nearly US $7,000,000,000.

Roger Henneberger: Mr. Henneberger's expertise includes: evaluation and assessment of geothermal resources; planning and management of geothermal exploration, drilling and well testing programs; technical and financial control of geothermal development and operations; wellsite geology, well testing, instrumentation and downhole measurements in geothermal wells; well targeting and design of directional drilling programs; design and management of computerized data bases; development of analytical and financial software; assessment of geological hazards; permitting and regulatory compliance; detailed petrographic and petrologic analysis; and geochemical sampling. He has conducted comprehensive assessments of the geothermal resources of Nicaragua, India, and the Republic of Armenia

James Lovekin: Mr. Lovekin has worked as a geothermal reservoir engineer since 1985 and joined GeothermEx in 1996. His expertise includes: planning and execution of geothermal well tests; assessment of geothermal reserves and sustainable reservoir capacity; interpretation of well logs, tracer tests, and geothermic trends; design and supervision of well workovers; prevention of scale in geothermal wells and surface facilities; selection of optimal injection strategies for geothermal fields; forecasting reservoir performance and estimating makeup drilling requirements; and budgeting and cost control for drilling and for monitoring reservoir performance. He has been responsible for planning field development and monitoring reservoir performance at numerous geothermal fields in the United States, Indonesia and Central America.