

Hawaii Renewable Energy Development Venture Technology Assessment Engineered Geothermal Systems

1. Overview

Although the deeper crust and interior of the Earth is universally hot, it lacks two of the three ingredients required for a naturally occurring geothermal reservoir: water and an interconnected open volume for water movement. Most aqueous fluids are derived from surface waters that have percolated into the earth along permeable pathways such as faults. Permeability is a measure of the ease of fluid flow through rock. The permeability of rock results from pores, fractures, joints, faults, and other openings that allow fluids to move. High permeability implies that fluids can flow rapidly through the rock. Permeability and, subsequently, the amount of fluids tend to decrease with depth as openings in the rocks compress from the weight of the overburden.

At shallow depths, typically less than 5 km, the coincidence of heat, water (usually with dissolved minerals and gases), and permeable rock can result in natural hot water reservoirs. These hydrothermal reservoirs have impermeable or low-flow boundaries such as structural discontinuities or other geological features that impede the migration of fluids. Often, hydrothermal reservoirs have an overlying layer or caprock that bounds the reservoir and also serves as a thermal insulator, allowing greater heat retention. If hydrothermal reservoirs contain sufficient fluids (water or steam) at high temperatures and pressures, those fluids can be produced through wells to generate electricity or, for process heat.

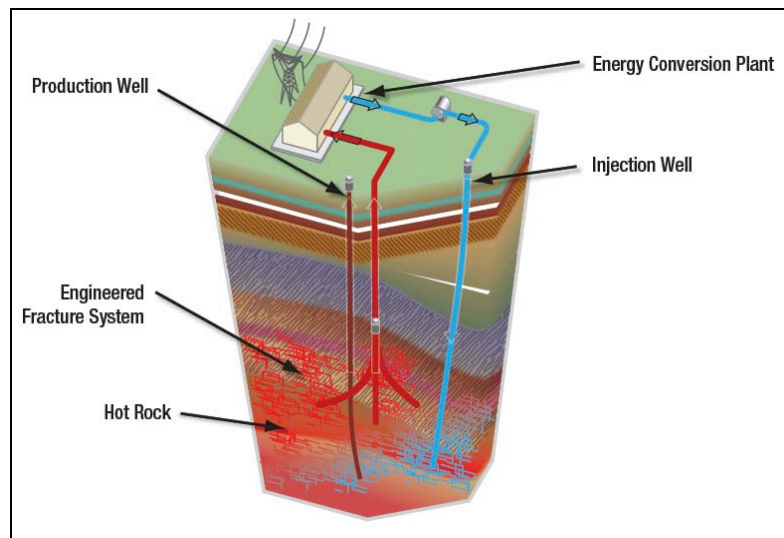


Figure 1. EGS Cutaway Diagram Energy Conversion Plant Injection Well Hot Rock Production Well Engineered Fracture System¹

¹ This diagram and much of the information in this section was obtained from a US DOE document entitled "2008 – An Evaluation of Enhanced Geothermal Systems Technology"

An alternative to dependence on naturally occurring hydrothermal reservoirs involves human intervention to engineer hydrothermal reservoirs in hot rocks for commercial use. This alternative is known as “Enhanced Geothermal Systems,” or EGS. EGS reservoirs are made by drilling wells into hot rock and fracturing the rock sufficiently to enable a fluid (water) to flow between the wells. The fluid flows along permeable pathways, picking up *in situ* heat, and exits the reservoir via production wells. At the surface, the fluid passes through a power plant where electricity is generated. Upon leaving the power plant, the fluid is returned to the reservoir through injection wells to complete the circulation loop (Figure 1). If the plant uses a closed-loop binary cycle to generate electricity, none of the fluids vent to the atmosphere. The plant will have no greenhouse gas emissions⁶ other than vapor from water that may be used for cooling.

2. Status of Commercial Readiness

There are many aspects of EGS that are already being applied. In California at The Geysers field, the oldest geothermal field in the U.S. and the largest geothermal venture in the world, operators have expanded the capacity of wells by injecting millions of gallons of reclaimed wastewater into the geothermal reservoir. Some experts call the Geysers wastewater project the first large-scale EGS project. There are several EGS projects that are already, or will soon, produce power:

- Soultz project, in France, a 1.5-MW EGS plant already in operation
- Landau project, in Germany, a 2-5 MW operational plant
- Paralana, in Australia, a 7-30 MW plant in drilling stages
- Cooper Basin, in Australia, a 1-MW showcase plant will be operational in 2008 and a 250-500 MW plant in drilling stages, expected to have the first 50 MW EGS plant operating as early as 2011-2012
- Desert Peak, in the U.S. (Nevada), in planning stages, the expansion of an existing natural geothermal field

2.1 EGS Well Drilling

Drilling is an essential operation in creating and sustaining EGS reservoirs. Today's oil and gas drilling technology can routinely reach depths of 4 to 5 km. An MIT study² concludes that drilling costs rise exponentially for oil and gas wells while costs for geothermal wells remain linear. Estimates of drilling costs with depth were calculated by a parametric cost model using a rather limited database from shallow wells. The assumption of *linear well cost with depth* is not realistic beyond 5 km, given the rigors of the geothermal environment (temperature, pressure, hard crystalline rock, reactive fluids) and current state of technology. Hence, the projected well costs with depth are considered optimistic.

The MIT study modeled improvements in drilling based on an analysis of experience gained through case studies. This concept of experience driving

² The MIT study can be downloaded at http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

improvements is termed the “learning effect.” While there are uncertainties in the impact of learning, available studies tend to validate the assumption that learning reduces well costs, especially within a given field. Although a number of technological improvements are examined which would reduce cost, those improvements are correctly not included in the economic analysis. Ultimately, drilling costs will have to be reduced.

2.2 Reservoir Creation

The MIT study assumed that the principal means of EGS reservoir creation will be hydraulic stimulation or the pumping of large volumes of fluids into the reservoir rock thereby fracturing the rock or opening pre-existing fractures. Hydraulic stimulation is a standard, mature technology, used in oil and gas fields to enhance production. This technology has been applied at all the EGS field projects to date with varied success. The MIT study contains an excellent summary of those stimulation experiments.

The key assumption associated with reservoir creation is that sufficient volumes of rock can be stimulated with enough fracture surface area and permeability to enable the extraction of large quantities of heat. This assumption has been corroborated by EGS field experiments around the world, notably at the Cooper Basin project in Australia where it has been proven (2009) that rock volumes on the order of cubic kilometers can be stimulated.

2.5 Reservoir Operation and Maintenance

The MIT study of reservoir performance under production conditions contains significant uncertainties that derive from reservoir geometry and permeability. The flow rate of circulating fluid in an EGS reservoir and the thermal drawdown associated with this flow rate are major unknowns. The analysis assumed *a flow rate of 80 kg/sec at 200°C from each production well*, equivalent to a commercial hydrothermal reservoir. This is a reasonable target, given that EGS reservoirs are intended to serve as enhanced or augmented hydrothermal reservoirs. At present there is no experimental evidence to verify that this level of productivity can be achieved. As pointed out in the analysis, the EGS project at Soultz has had a maximum well productivity of about 25 kg/s. Well productivity remains the greatest technological challenge for the commercialization of EGS.

Besides productivity, the analysis assumed that the fracture system will provide sufficient thermal stability for long-term production. This derives from the total effective surface area of the reservoir. The MIT study assumed a conservative reservoir lifetime of six years, where lifetime is defined as a 10°C decline in fluid production temperature, after which the reservoir would have to be re-drilled and re-stimulated. This temperature decrement is conservative because greater amounts of cooling have been observed in commercially operating reservoirs. The reservoir lifetime and other parameter values for the base case EGS economic models are unknown in that no

commercial-scale EGS plant has operated with sufficient thermal drawdown to establish reliable lifetime performance data.

The analysis assumed that the system loses up to 2% of total injectate during reservoir operation. For some systems, the cost of water could dominate stimulation costs. Water losses during operation are also a potentially important cost. Lacking knowledge about water consumption in various EGS environments, the assumption to limit water losses is optimistic if water must be accounted for in project costs.

For energy conversion, the assumption was that the engineering systems would be the same as those used for liquid-dominated hydrothermal resources at similar temperatures (flash steam and binary power cycles). This is a reasonable assumption since differences between fluids produced from hydrothermal and EGS reservoirs should be minimal once chemical stability is attained during circulation. The thermodynamic analyses are based on well-understood and well-founded theory and data. Because energy conversion efficiencies have a linear influence on the calculated recoverable resource, errors in assumed energy conversion efficiencies may represent a minor source of error in resource calculations. The overall approach and the cost and performance results obtained are sound.

2.6 EGS Economics

Every element of the economic analysis has a different level of risk and different calculation requirements. Assumptions were made regarding many parameters for each EGS system element, including reservoir productivity, drilling, plant cost, resource depth, interest rates, and so forth. Interconnection with the power grid was assumed not to be an issue. Although stimulation and reservoir connectivity remain as major issues, reservoir creation efforts are assumed to be consistently effective. The technical parameters with the highest uncertainty and risk are flow rate per production well and thermal drawdown rate (i.e. reservoir lifetime.)

The analysis includes different learning curves for each technology element. The learning curve for achieving 80 kg/sec flow rates was assumed to be a one-time effect that is achieved fairly quickly. The opinion of the experts in the workshops was that learning curves based on oil and gas experience may be optimistic for EGS well drilling. The study uses an equity rate of return of 17%, which corresponds to a fairly risky venture. The drilling cost model uses a conservative contingency factor of 20% for trouble costs. For this type of economic modeling, the surface plant design is not specified in detail, so correlations must be used. Taken in total, the learning curve for plant costs is somewhat optimistic, and the long-term cost was based on the judgment of the MIT panel. Sensitivity analyses were performed to identify the variables most responsible for uncertainty and risk.

Some important assumptions were made regarding future baseload supply and demand. Of the 90 GWe of nuclear power in the existing

power plant fleet, about half are assumed to be retired in the time frame of the study, and about 50 GWe of coal generation is also projected to be retired. This turnover in existing plant inventory provides an opportunity for replacement with EGS, concomitant with the development goal of 100 GWe³.

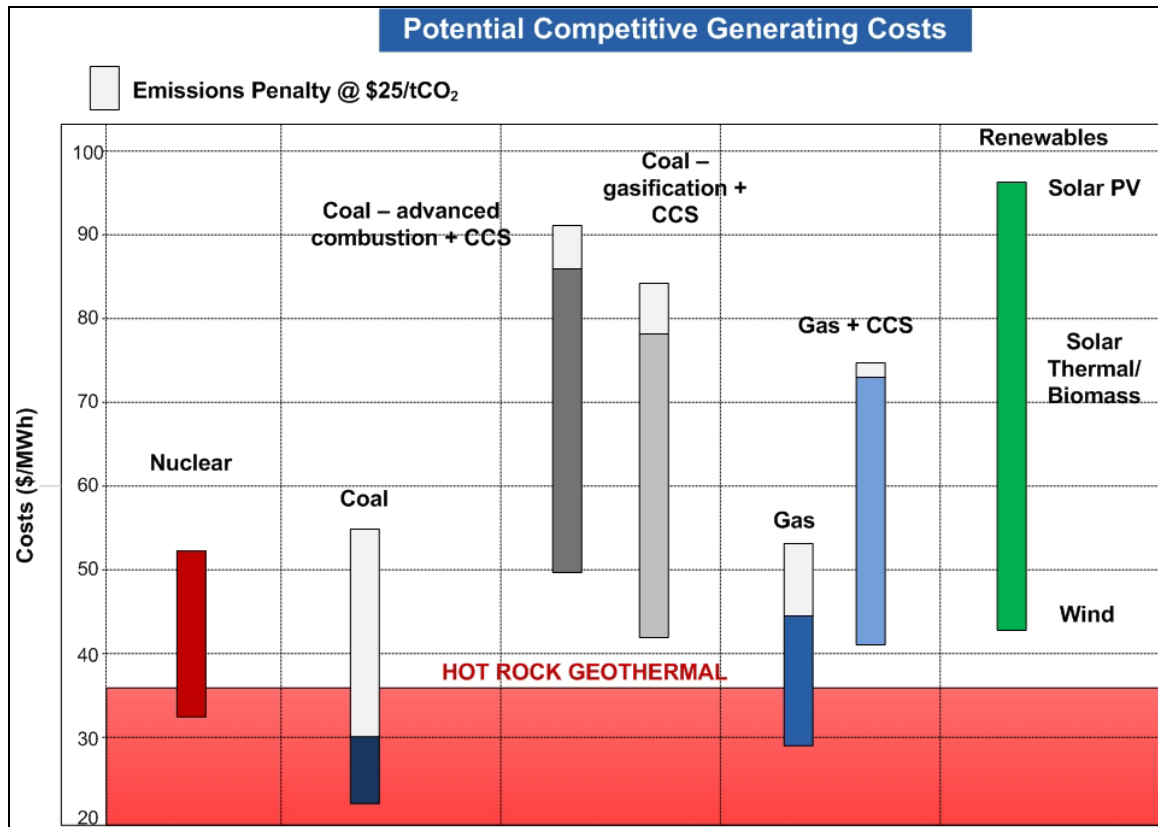


Figure 2. EGS Economic Analysis

3. Appropriateness for Hawaii

3.1 Geothermal Resources

A 1983 geothermal resources map⁴ (Figure 3) shows there are several potential geothermal resources on all islands with the exception of Kauai. The major geothermal resource is at Puna on the Big Island and is already being commercially exploited, although not to its full potential. However, the Puna resource is geographically separated from Oahu, Hawaii's major energy user. Therefore it is of great interest that there are two areas on Oahu, Waimanalo and Waianae, that have warm geothermal temperatures of 50°C or lower. The question to be answered is their potential as viable geothermal resources at greater depths. This will require new thinking and prospecting

³ Adapted from Geodynamics Limited – Annual Report 2007

⁴ <http://geothermal.id.doe.gov/maps/hi.pdf>

efforts to get more information on the resources and would include drilling exploratory/research wells to further delineate the resource. There are similar "warm spots" located on the islands of Maui and Molokai and it could be worth an effort to revisit Kauai.

It is noted that Iceland is currently drilling a two and one half mile geothermal well into an active volcano crater that could potentially generate an endless supply of clean energy according to an article in Popular Science.⁵ The well is twice as deep as any geothermal well in the world. It is a keystone effort to extract "supercritical" water that is very hot (1,100°C) and under immense pressure. If this resource can be tapped, it would provide an order of magnitude increase in the amount of power Iceland could obtain compared to its normal geothermal resources. According to the article, if the gamble pays off, it could catapult Iceland out of debt and revolutionize renewable energy efforts around the world. As a point of reference, the investment in the Iceland Deep Drilling Project (IDDP) is about \$22 million. The project's risk assessor gives it a 50-50 chance of succeeding, however if it works, the well could deliver as much power as a small nuclear power plant (500 megawatts). And the real payoff is the IDDP's zero-emissions power source will last as long as the Earth's core continues to heat water. Further information on the Iceland project is available at <http://www.iddp.is/>.

It appears that Iceland is leading the way and it might be a good investment for Hawaii to follow their lead.

⁵ <http://www.popsci.com/environment/article/2009-06/icelands-power-down-below?page=>

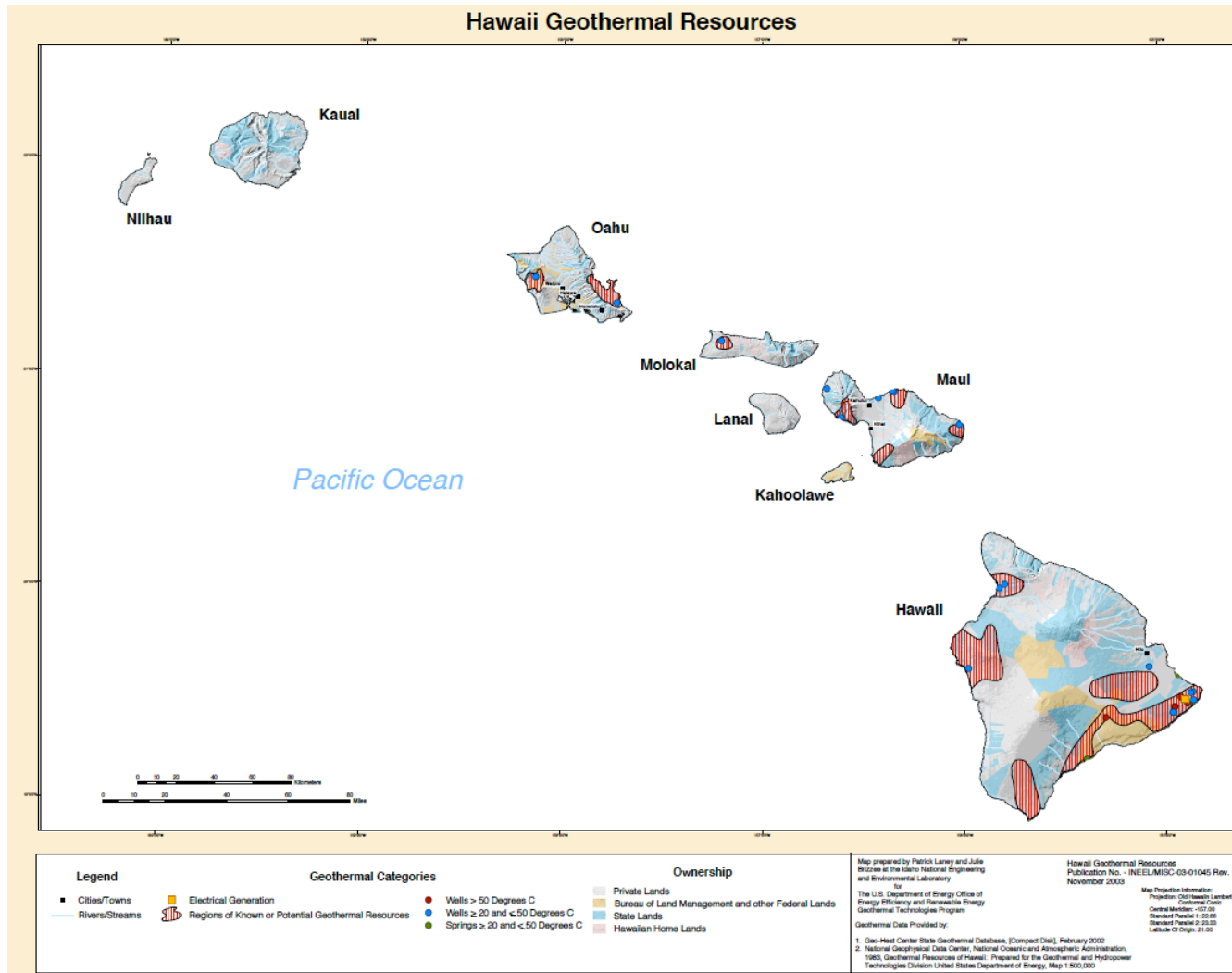


Figure 3: 1983 Geothermal Resource Assessment

4. Considerations related to specific technologies and/or resources

4.1 Financing Projects

The financing required to implement a geothermal is not trivial. Full-scale EGS development requires an investment of about \$50M to \$100M per site. The current financial market situation is serious: 1) the tax equity market has dried up, 2) there is limited availability of debt financing and limited investor interest in early stage projects, and 3) big banks that traditionally financed or invested in renewable energy projects have either gone under or have been kept afloat by bailout programs both in the U.S. and internationally. The sector did see some modest venture investments last year in EGS-related companies but generally it has stagnated in 2008 and there are likely to be fewer investments in 2009. Private equity investments currently favor cash-generating assets, which makes it difficult for projects in development (such as EGS projects) to get financing. On the project financing side, most of the big players in this market are now reluctant and are applying their resources very selectively, which will make it difficult for geothermal developers.

On the positive side, the provisions of the U.S. stimulus package has been very encouraging including:

- ✓ Extension of production tax credits;
- ✓ Availability of investment tax credits;
- ✓ The possibility of cash grants up to 30% of development costs;
- ✓ New capital structures are available with different models for investors who can now benefit despite not having a taxable income.

Oil price increases have in the past spurred geothermal development, while decreases have had a negative impact. Therefore current low prices have been a concern, but are not expected to last. Oil prices are expected to increase slightly until 2010, and the IEA estimates oil prices of USD 200/barrel by 2013. There is even increased interest in geothermal development by oil players, so that can be taken as a good sign.⁶

4.2 What laws govern geothermal energy?

Geothermal energy production and use are governed by numerous federal, state, and local laws ranging from environmental protection statutes to zoning regulations. Unique laws at the federal and state level govern the leasing and permitting of geothermal resources on federal and state land. Federal lands geothermal leasing is governed by the John Rishel Geothermal Leasing Amendments passed as part of the 2005 energy bill. These provisions are codified in Title 30, Chapter 23 Sections 1001-10028 of the U.S. Code. This

⁶ "Financing Geothermal Projects in Challenging Times" – Islandsbanki geothermal research report dated April 2009

can be accessed online through the House of Representatives Web site (<http://uscode.house.gov>), or through other law sources such as Cornell Law School's online directory.⁷

At the state level, the most important laws are the renewable portfolio standards (RPS) that require utility companies to have a growing percentage of renewable power generation in their mix. About 43 states today have some form of RPS requirement. In addition to this, states offer a wide range of additional rules, policies and incentives for renewable generation. A database of state incentives is available online at: <http://www.dsireusa.org>.

At the federal level, tax incentives are usually considered the most important renewable incentive. Geothermal power projects can qualify for either the federal Investment Tax Credit or the Production Tax Credit. In addition, there are loan and grant programs, research support, and other federal measures encouraging geothermal and other renewable technologies. The database noted earlier also has a listing of federal incentives with links to information sources about each. (<http://www.dsireusa.org>)

Federal research programs also support geothermal energy. The Geothermal Research Development and Demonstration Act, passed by Congress in 1974, establishes a wide range of policies from loan guarantees to educational support, but while the statute remains on the books it is largely not in effect. (See Title 30, Chapter 24, Sections 1101 et seq of the U.S. Code.) More recently, Congress has passed as part of HR 6 in 2007, the Advanced Geothermal Energy Research and Development Act of 2007. Additional information about the underlying legislation and links to the final provisions as enacted are available at: http://science.house.gov/legislation/leg_highlights_detail.aspx?NewsID=1828.

The economic stimulus bill includes a range of provisions intended to support expanded geothermal energy use, from power plants to geothermal heat pumps. Among the most important according to GEA are the bills tax credit provisions.

The stimulus bill will extend the production tax credit for new geothermal power plants through 2013, allow developers to take a 30% investment credit instead, and create a cash grant program to support projects that cannot utilize a tax credit in the current market. It also expands the Clean Renewable Energy Bond program that provides similar incentives for coops and public power agencies to build new geothermal and other renewable technology projects.

The legislation also dramatically expands support for the Department of Energy's geothermal research, development, demonstration and deployment efforts. The Bush Administration had sought to close down these

⁷http://www4.law.cornell.edu/uscode/html/uscode30/usc_sup_01_30_10_23.html

efforts, but Congress authorized a broad, new advanced geothermal research program in 2007 as part of the energy bill and has now provided the funds to carry it out. The stimulus bill sets aside \$400 million for geothermal technology research, development and deployment efforts at DOE.