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ENHANCED GEOTHERMAL SYSTEMS R&D IN THE UNITED STATES

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ABSTRACT

Enhanced Geothermal Systems (EGS) are those in which advanced technology is required to extract energy from the earth's crust in areas with higher than average heat flow but where the natural permeability and/or fluid content are limited. In the United States, the Department of Energy (DOE) is conducting EGS research and development (R&D) with two major goals. Its short-term goal is to enable greater efficiency and sustainability in the extraction of heat energy from commercial hydrothermal fields. Its long-term goal is greater utilization of the vast geothermal resource base to offset the environmental hazards associated with other forms of energy. The EGS research strategy includes close cooperation with industry to plan and execute research to overcome the technical barriers that prevent the recovery of increased quantities of geothermal energy. To this end, federally funded EGS research is ongoing, and DOE is planning to issue a solicitation late in fiscal year 1999 or early fiscal year 2000 for additional research. Laboratory and field experiments are anticipated to continue in fiscal year 2000, and will focus on cost-effective methods to: 1) convert dry holes for use as injectors or producers, and connect these holes to the permeable reservoir; and 2) increase the rate of injection to sustain fluid-depleted reservoirs.

1. Introduction

Geothermal energy is abundant in many parts of the world and can play a vital role in domestic and international energy supply and efforts to reduce greenhouse gas emissions and slow global climate change. The U.S. Department of Energy is exploring this possibility through its R&D initiative for Enhanced Geothermal Systems (EGS). Enhanced Geothermal Systems are those in which advanced technology is required to extract energy from the earth's crust in areas with higher than average heat flow but where the natural permeability and/or fluid content are limited.

It is difficult to determine how much geothermal energy is accessible with current technology, or would be accessible with enhanced technology. However, experts estimate that up to 6 GW in the U.S. and 72 GW worldwide could be produced with current technology at known hydrothermal sites. With enhanced technology, these estimates increase to 19 GW and 138 GW (Gawell, et al, 1999). It is important to note that these estimates are limited to known hydrothermal sites, which represent only a miniscule fraction of the accessible heat in the upper crust. The U.S. Geological Survey has calculated the heat energy in the upper 10 kilometers of the earth's crust in the U.S. is equal to over 600,000 times the country's annual non-transportation energy consumption (Sass and Lachenbruch, 1979). Probably no more than a tiny fraction of this energy could ever be extracted economically. However, just one hundredth of 1% of the total is equal to half the country's current non-transportation energy needs for more than a century, with only a fraction of the pollution from fossil-fueled energy sources.

It is this potential that the Department of Energy seeks to eventually unlock through its EGS R&D. The initiative seeks to increase the accessibility of greater quantities of geothermal energy by developing enhanced technology. Such technology will initially enable greater efficiency and sustainability in the extraction of heat energy from producing hydrothermal fields by either enhancing low-permeability areas within or around the field, and/or by artificially recharging fields that have been depleted as a result of production. The technology developed initially will set the stage for eventually recovering the abundant heat contained in areas not associated with commercial hydrothermal fields.

2. Background

DOE has integrated the EGS R&D Initiative as the long-term, higher-payoff component of its geothermal energy strategy. One of the goals outlined in DOE's Strategic Plan for the Geothermal Energy Program (US Department of Energy, 1998) is to develop new technology by the year 2010 to meet 10% of the U.S. non-transportation energy needs in subsequent years. The EGS R&D Initiative is a key element in the strategy to achieve this goal.

Two shifts in thinking about geothermal energy and related technology development are inherent in the strategy for the EGS R&D Initiative. First, although naturally occurring hot water or steam has been the resource tapped by geothermal developers to date, there is a growing awareness that heat energy contained in subsurface rock is a much larger resource. The Geysers geothermal field in northern California is a good example. After nearly 30 years of steam production, and especially after substantial power plant expansion in the 1980s, the geothermal fluid content in the reservoir has declined significantly. As a result, there has been a large decline in production of the field, which is generating at about 60% of the installed capacity. However, it is probable that only a very small fraction (perhaps up to about 5%) of the heat in the reservoir rock has been extracted.

Second, previous research efforts to extract geothermal energy at the extreme end of the permeability spectrum, in nearly impermeable crystalline basement rock (at Fenton Hill, New Mexico) demonstrated that developing a project relying upon artificially created permeability alone is overly ambitious at present for two reasons: 1) the technical difficulty of creating enough heat-transfer area; and 2) project economics, given present competitive power markets. The EGS R&D Initiative adopts an incremental approach to

research that is more compatible with the natural evolution of the geothermal industry. Industry will logically develop the highest quality resource sites first and develop sites with progressively lower permeability and/or fluid content as the necessity and opportunity for such coincide. Thus, it is appropriate to initially focus EGS technology development in and adjacent to hydrothermal reservoirs with incremental expansions of effort to more geologically challenging areas over time.

These initial efforts will seek to develop new technology to convert dry holes for use as injectors or producers. It is not uncommon for wells in producing geothermal fields to intersect zones of high temperature but low permeability. At a cost of up to $3 million per well, this represents a significant stranded asset. Cost-effective methods to connect these wells to the permeable reservoir, either through targeted re-drilling or well stimulation, will be sought. The idea of utilizing dry or marginally productive wells was among several criteria developed for EGS experimental sites at the EGS Dual-Use Workshop conducted by DOE in Berkeley, California in April 1998 (Princeton Economic Research, 1998). Initial field experiments will also be directed toward recharging geothermal reservoirs that have become depleted as a result of production, as is presently being undertaken through augmented injection at The Geysers.

3. EGS R&D Strategy

In October 1997, DOE selected a team of private contractors, Princeton Economic Research, Inc and GeothermEx, Inc. (PERI/GX), to manage the EGS R&D Initiative. The initial work of the team has been to forge an industry advisory group, develop strategy, and define technical objectives. The industry advisory group, titled EGS National Coordinating Committee (NCC), began in early 1998 and currently has seven members. The purpose of the NCC, as stated in its charter, is:

> "… to help ensure that the federal government's geothermal research and development program addresses the most critical technological barriers and achieves a balanced focus on near-term industrial objectives and longer-term national environmental and energy-supply objectives. The Committee will pursue this purpose by providing DOE's EGS R&D Contractor with industry insight, technical information, expert opinion, specific analyses and evaluations, and recommendations that will benefit the planning, management, and execution of EGS research."

The Committee was instrumental in helping DOE and the PERI/GX team to develop the EGS Strategic Roadmap (US Department of Energy, 1999). The Roadmap relates to the long term component (Goal 5) of DOE's Strategic Plan for the Geothermal Energy Program. The Roadmap identifies the technical barriers faced by industry in making greater quantities of geothermal energy more accessible and emphasizes a government/industry partnership approach to overcoming these barriers. The key element in the strategy is to begin attacking the barriers at the more permeable end of the spectrum. Thus, the strategy includes goals that will benefit industry in the near-term, while also working toward longer-term goals intended to serve national energy, economic, and environmental interests.

The strategy recognizes that many of the technology improvements necessary for EGS (such as locating and understanding fractures and fracture-based permeability) will also be applicable to hydrothermal developments, and the EGS R&D Initiative is working closely with DOE's Reservoir Technology Initiative to coordinate research efforts. Although drilling and heat conversion technologies are important for EGS, they are not included as components of the EGS Initiative because they are covered under other initiatives within the Office of Geothermal and Wind Technologies. The importance of close communication and coordination with these other initiatives is clearly recognized.

The EGS Roadmap includes several strategic milestones that focus on overcoming the technical barriers to EGS development. The earlier milestones include organizing the EGS initiative, engaging industry, and beginning laboratory and field experiments. Accomplishment of these milestones is well underway with the completion of a rational strategy, cooperation and participation by industry, and on-going work (see Section 5 below).

Based on the strategy, by 2004, five prospective EGS sites will be selected and projects initiated. By 2008, a pilot-scale, demonstration project at an EGS site will be completed and begin a two year period of operation. Although it is likely this project will be located within or adjacent to a commercial hydrothermal development, this is not a requirement. Current sentiment is for the demonstration project to be located on the periphery of a hydrothermal field and support production to an existing plant. However, a stand-alone application (locating the project outside a commercial hydrothermal field) has not been precluded. A stand-alone application, if implemented, would more likely be located in a geologic setting with some permeability and fluid (like the Soultz or Ogachi experimental sites in France and Japan) rather than in a setting similar to Fenton Hill. After two years operation, the results of the pilot project will be analyzed to support conclusions regarding the technical and economic feasibility of this type of project.

Accomplishing these milestones will lead to greater success for the geothermal industry. Specifically, new technology will:

- enable industry to convert some dry (non-commercial) production and injection wells into commercial wells at less cost than drilling a new well;
- provide industry with better tools for managing injection strategies, including fluid augmentation, to ensure the sustainability of geothermal developments;
- create opportunities at some existing hydrothermal projects to expand the boundaries of the field, thus recovering additional heat;
- demonstrate the predictability and sustainability of Enhanced Geothermal Systems such that developers, investors, and financiers will have the confidence to participate in such projects; and

- create new opportunities for developers beyond those provided by the hydrothermal resources developed for commercial power generation to date.

4. EGS Technical Objectives

DOE and PERI/GX, with the aid of the National Coordinating Committee, has developed a preliminary set of technical objectives for the EGS R&D Initiative. It is expected that these objectives may change somewhat as the Initiative evolves. The objectives focus on understanding and manipulating permeability and hydrology. Improving the understanding of permeability and hydrology is primarily the responsibility of DOE's Reservoir Technology Initiative. Improving technology to manipulate and enhance permeability and hydrology is the responsibility of the Enhanced Geothermal Systems Initiative. Manipulating permeability and hydrology require a solid understanding of the nature of both. Therefore these two initiatives are closely related and their technical objectives are somewhat intertwined. The two initiatives will be managed to complement each other, including some overlap and sharing of responsibilities between the two. Table 1, below, offers a brief overview of the EGS technical objectives.

5. On-Going Projects

During 1999, three significant projects are under way:

- Dixie Valley – Investigators from the U.S. Geological Survey, Stanford University, and Oxbow Power Services have been studying the relationships between stress, fractures, heat flow and hydrology in the Dixie Valley geothermal system in northern Nevada. Siting wells there has been problematic because areas of high and low permeability exist adjacent to one another in the field. Tests and logs of several unsuccessful wells have indicated commercial reservoir temperatures, weak pressure communication with the reservoir, and very low permeability. The work has focused on determining the reasons for permeability variations within the field, exploring whether such variations can be predicted from surface or borehole measurements, investigating whether unsuccessful wells can be reclaimed through stimulation, and developing methods to determine whether redrills of unsuccessful wells are likely to be successful. The current work focuses on well 82-5, which has four unsuccessful legs despite being located between two successful wells. Data gathering and operations will include a borehole televiewer log; temperature, pressure, spinner, gamma ray logs collected during injection; a mini-hydrofrac; and static temperature and pressure logs. The data obtained will be integrated with previous data and analyzed to determine why well 82-5 did not encounter high permeability and whether the well might be suitable for stimulation experiments involving massive hydraulic fracturing. The work was suspended due to well problems in the summer of 1999. An evaluation of whether to continue the project is pending.

- GeothermEx, Golder Associates, and Kansas State University are assessing the state-of-the-art of numerical simulation of enhanced geothermal systems. The study assesses the applicability of current hydrothermal reservoir simulators to EGS reservoirs, evaluates the applicability to EGS problems of advances in discrete fracture network models of groundwater contaminant transport and nuclear waste disposal, and makes recommendations for continuing research and development in numerical simulation in the context of enhanced geothermal systems. This work was completed in the summer of 1999.

- PERI/GX began the process of indexing and archiving data and information from the DOE Hot Dry Rock experiment at Fenton Hill. The current work includes building a relational database system that links all the Fenton Hill data, activities, and technical reports published by Los Alamos National Laboratory. The work also recommends priorities for archiving data sets, including recommendations about which data sets might be useful for future developers of EGS, and makes recommendations regarding the archiving process. This task was completed in the fall of 1999.

6. International Cooperation

Cooperation with foreign scientists involved in similar R&D is another key component of the EGS R&D strategy. Japanese and European organizations have long been active in this area of research and are conducting long-term investigations with considerably greater funding than has been available in the U.S. International cooperation and coordination are necessary to share technological advancements for the common good, to avoid duplication of effort, and to leverage limited resources.

Cooperation is conducted under the framework of the Geothermal Implementing Agreement sponsored by the International Energy Agency. The Agreement promotes:

- international scientific collaborative efforts to compile and exchange improved information on geothermal energy research and development worldwide concerning existing and potential technologies and practices;

- development of improved technologies for geothermal energy utilization; and

- better understanding of geothermal energy's environmental benefits and ways to avoid or ameliorate its environmental drawbacks.

The Agreement was implemented in mid-1996 and has been signed by the Commission of the European Communities, Japan, New Zealand, United Kingdom, and United States. Recent cooperation has included several activities. Peter Rose, Energy & Geosciences Institute, has conducted tracer studies at the Soultz experimental hot dry rock project. Dan Swenson, Kansas State University, has been involved helping Japanese researchers plan flow tests at the Hijiori research site. Jorg Baumgartner, project director of the hot dry rock experiment at Soultz, participated in the U.S. EGS Dual-Use Workshop in Berkeley, California in April 1998. To remain current regarding European and Japanese advances in EGS technology, researchers and managers from DOE, PERI/GX,

Energy & Geosciences Institute, Kansas State University, and Massachusetts Institute of Technology attended the 4th International HDR Forum in Strasbourg, France in 1998. Several of the U.S. contingent presented papers on DOE's EGS R&D Initiative.

7. Future Plans

Solicitations for EGS proposals will continue, depending on funding. Such solicitations will probably be broad-based, seeking proposals primarily concerned with field and laboratory work related to enhancing production in or adjacent to commercially productive hydrothermal fields. It is planned that current efforts will lead to significant stimulation and injection augmentation field experiments in fiscal years 2000 and 2001.

In addition, the DOE is interested in basic science studies in the areas of rock fracturing and other well stimulation technologies, predictive and modeling technologies for sub-surface stimulation processes, rock mechanics and its relationships to well stimulation and fluid flow, and fracture identification and characterization.

Also, DOE is interested in continuing to support U.S. scientists and engineers in cooperative EGS research with colleagues overseas.

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Table 1. Enhanced Geothermal Systems R&D Technical Objectives

	Permeability	Hydrology
Understanding	➢ Develop and refine methods to locate and characterize permeable fracture systems at reservoir depths ➢ Improve understanding of the manner in which fracture geometry and permeability are controlled by in-situ stress, lithology, structural setting, and tectonic history ➢ Create better surface and borehole methods for imaging subsurface hydrologic and thermal conditions, geologic structures and in-situ stress state	➢ Improve understanding of the hydromechanical response of geothermal reservoirs to production and injection of produced fluid and its impact on long-term reservoir performance ➢ Develop improved tracer testing and other methods to determine the nature and extent of time-dependent changes in reservoir hydrology induced by production and injection ➢ Improve methods to predict the impacts of augmented injection on reservoir performance and life span
Manipulating	➢ Using improved conceptual models for permeability in fracture-dominated reservoirs, develop and improve upon well stimulation and enhanced recovery techniques for use in geothermal environments ➢ Refine existing techniques for monitoring and characterizing the effects of geothermal reservoir stimulation efforts (e.g., tilt and microseismic monitoring and tracer studies) ➢ Develop improved computational methods for predicting the success of well stimulation efforts under realistic geothermal conditions	➢ Develop improved injection strategies, including augmented injection, to maximize heat extraction and sustainability ➢ Develop improved methods for siting production and injection wells ➢ Develop improved well drilling and completion strategies to optimize hydraulic communication between wells and natural and man-made fracture systems (especially deviated wells)