GEOHERMAL PROGRAM REVIEW VIII

"The National Energy Strategy The Role of Geothermal Technology Development"

ABSTRACTS

Sponsored by:

**U.S. Department of Energy
Assistant Secretary, Conservation and Renewable Energy
Geothermal Technology Division**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

	<u>Page</u>
Hydrothermal Energy Conversion Technology	1
Hydrothermal Reservoir Technology	6
Hydrothermal Hard Rock Penetration Technology	10
Hot Dry Rock Technology	13
Geopressured-Geothermal Technology	16
Magma Energy Technology	21

**HYDROTHERMAL ENERGY - AN IMPORTANT PART OF
AMERICA'S ENERGY STRATEGY**

Kenneth J. Taylor
Idaho Operations Office

Marshall Reed
U.S. Department of Energy

Howard Ross
University of Utah Research Institute

The U.S. Department of Energy established a Geothermal Energy Program in the mid-1970's as one response to America's need to develop alternative energy sources. One element within the Geothermal Program is Hydrothermal Energy, which includes Industrialization, Reservoir Technology, and Conversion Technology as separate tasks. The successes which have resulted from this program, combined with anticipated future progress, will increase the role of geothermal energy as a contributor to our nation's future energy needs. Geothermal energy has become an important component of the U.S. National Energy Strategy.

**ADVANCED BINARY GEOTHERMAL POWER PLANTS --
LIMITS OF PERFORMANCE**

**C. J. Bliem and G. L. Mines
Idaho National Engineering Laboratory**

The Heat Cycle Research Program is currently investigating potential improvements to power cycles that utilize moderate temperature geothermal resources to produce electrical power. The technology being considered either improves the performance of the power cycle and reduces the cost of electricity, or it provides a means of utilizing a resource which might otherwise not be used because of institutional or technical barriers. Although geothermal energy is provided by nature, it is generally expensive to produce, and compared to fossil fuel is a low grade energy source. Because of the low quality and high cost of the energy, optimized systems using this resource for the generation of electrical power should utilize as much of the energy contained in a unit mass of the fluid as possible. This optimization was confirmed with both a "value analyses" study and a "market penetration" study which examined the impact of performance improvements on the cost of electricity and on the future utilization of geothermal produced electrical power if these improvements could be realized. The net brine effectiveness, or the net electrical energy produced by the plant per unit mass of brine, is used as a primary indicator of the improvements in the cycle performance.

The Heat Cycle Research Program investigated Rankine cycle binary power systems. This system was selected because binary Rankine cycles are more efficient than the flash steam cycles for moderate temperature resources and achieve a higher net brine effectiveness. The program has examined those operating conditions, working fluids, and component designs that will provide the optimum binary cycle performance, recognizing that as the resource temperature changes, the cycle parameters will also likely change. At resource conditions similar to those at the Heber binary plant, the work in the research has shown that mixtures of saturated hydrocarbons (alkanes) or halogenated hydrocarbons operating on a supercritical Rankine cycle give performance improvements over corresponding pure working fluids.

Recently, other types of cycles have been proposed for binary geothermal service. This paper explores the limits on efficiency of feasible plants using the advanced concepts developed in the Heat Cycle Research Program and other advanced cycles.

Programmatic R&D Objective: Heat Cycle Research Project objectives.

Potential Technologies/Innovations Expected: Improved binary power cycles performance, design basis for heat exchangers using mixed working fluids, less water consumptive heat rejection systems.

Potential User Group(s): Geothermal power plant developers.

Expected Time Frame for R&D Completion: 1993.

DOE HQ Program Manager: Raymond LaSala

ADVANCED MATERIALS DEVELOPMENT

Lawrence E. Kukacka
Brookhaven National Laboratory

Before geothermal energy can make a significant contribution to the nation's energy supply, improvements in its economic and technological viability must be made. The continued development and utilization of advanced materials of construction will help to attain these goals. To address these needs, emphasis is being placed on materials which will substantially reduce the cost of drilling and completion, and for energy conversion. Successful developments will also result in improved safety and lessen the environmental impacts of geothermal development. High priority needs are for advanced high temperature lost circulation control materials, carbon dioxide resistant lightweight cement well completion materials, and tools such as drillpipe protectors, rotating head seals, blow-out preventors, and downhole drill motors. The lack of suitable hydrolytically stable chemical systems that can bond previously developed elastomers to metal reinforcement is a critical but as yet unaddressed impediment to the development of these tools.

The availability of low cost, thermally conductive, corrosion- and scale-resistant tubular lining materials for use in shell-and-tube heat exchangers and other components, would greatly enhance transport and energy extraction processes utilizing hypersaline brines, and possibly increase the exploitable low temperature geothermal energy reserves for commercial development. Work to address all of these materials needs is underway at Brookhaven National Laboratory. Recent developments, and plans for the coming year are summarized in the paper.

Programmatic R&D Objective: Reductions in costs for well drilling, completion, and energy conversion by the availability of improved materials.

Potential Technologies/Innovations Expected: Lightweight CO₂-resistant cements, lost circulation control materials, elastomers, thermally conductive composites.

Potential User Groups(s): Service companies, producers, utilities, tool manufacturers.

Expected Time Frame for R&D Completion: Ongoing; Cements 1992, Lost Circulation 1992, Heat Exchanger Tubes 1991, Elastomers 1993.

DOE HQ Program Manager: Raymond LaSala

DEVELOPMENTS IN GEOTHERMAL WASTE TREATMENT BIOTECHNOLOGY

Eugene T. Premuzic, Mow S. Lin, and Sun Ki Kang
Brookhaven National Laboratory

Technical feasibility of a technology based on biochemical processes for the conversion of geothermal wastes from hazardous to non-hazardous wastes has been demonstrated. Laboratory scale studies have shown that biotechnology for detoxification of geothermal wastes is versatile and is applicable to a variety of geothermal sludges containing few or many metals whose concentrations may exceed limiting threshold concentrations as recommended by regulatory agencies. Metals such as chromium, copper, manganese and others, can be removed with 80-90% efficiencies. Continuing studies aimed at optimization and scaling up of processes used in the emerging biotechnology indicate that there are several essential process variables which have to be considered in the development of geothermal waste treatment biotechnology. Some recent studies dealing with process variables will be discussed.

Programmatic R&D Objective: The overall objective of this program is to reduce the costs associated with the surface disposal of residual sludges derived from geothermal brines. This is to be accomplished by development of environmentally satisfactory technology.

Potential Technologies/Innovations Expected: A novel technology based on biochemical processes for solubilization of toxic metals is being developed. The emerging biotechnology for the detoxification of geothermal brines meets environmental requirements and is both technically and economically feasible.

Potential User Group(s): Geothermal industry and other industries' agencies dealing with environmental problems.

Expected Time Frame for R&D Completion: On-going; subject to the level of funding and industrial collaboration.

DOE HQ Program Manager: Gladys Hooper

CHEMICAL MODELS FOR OPTIMIZING GEOTHERMAL POWER PRODUCTION

John Weare, Nancy Moller, Zhenhao Duan
University of California, San Diego

The purpose of the UCSD Brine Modeling Program is to develop technology which will improve the efficiency of geothermal operations. We are constructing computer models which can evaluate the energy content and the likelihood of scale formation of geothermal brines with their associated gas phases under a wide variety of operating conditions (species, temperature, pressure). Our present model, with a temperature range of 0°-250°C, can predict calcium carbonate, calcium sulfate, and amorphous silica scale formation as a function of brine composition and partial pressure of CO₂. It can also predict the presence of other less common scales, such as sodium chloride. This model is now ready for testing on industry problems. A Macintosh version, which will be available to the geothermal community, is under development.

New developments include improvement of the representation of mixed gas phase behavior in high pressure formations. We now have modeled the thermodynamic behavior of gaseous mixtures in the CO₂(g)-CH₄(g)-H₂O(g) system from 0°-1000°C and from 0-3500 atm. These ranges in P and T allow application to geopressured systems. This model can be used to calculate the energy content (dissolved methane) and scaling tendency under the high pressures experienced in these systems.

Progress has also been made in modeling the behavior of the H₂S-H₂O system. Using a reliable representation of the gas phase (Redlich - Kwong), a model which predicts the solubility and gas phase thermodynamics for this system for temperatures from 0°-90°C and for pressures from 0-60 atm has been developed. The T and P range is limited by the lack of high temperature data. This preliminary model may be used in engineering studies of the abatement of H₂S and will eventually be part of a model of sulphide scale deposition.

We are continuing efforts to incorporate more species that are important for geothermal applications. In addition, we are adapting our codes for dissemination to the geothermal community. The theoretical developments necessary to include nonideal gas phases (highly pressured gas phases) in the total system free energy expressions--necessary to predict breakout in high pressured systems--are progressing. Models of the solubility of the gases, methane and carbon dioxide, in concentrated brines should be available soon.

Programmatic R&D Objective: Reduction of the user cost of geothermal energy by controlling scale formation and predicting the energy content of brines.

Potential Technologies/Innovations Expected: Development of a model of brine thermodynamics applicable to high temperature, pressure, and concentration.

Potential User Group(s): Geothermal developers.

Expected Time Frame for R&D Completion: Three years

DOE HQ Program Manager: Gladys Hooper

**RESERVOIR TECHNOLOGY RESEARCH AT LBL ADDRESSING
GEYSERS ISSUES**

M. J. Lippman and G. S. Bodvarsson
Lawrence Berkeley Laboratory

The Geothermal Technology Division of the Department of Energy (DOE) is redirecting a significant part of its research efforts to study problems currently experienced at The Geysers. These problems include excessive pressure drawdown and associated decline in well flow rates, corrosion due to high chloride concentrations in the produced steam and high concentrations of noncondensable gases in certain parts of the field. Lawrence Berkeley Laboratory (LBL) is addressing some of these problems through field, laboratory and theoretical studies.

Laboratory studies are being conducted in order to determine two-phase relative permeabilities of fractures. A casting technique has been developed for making translucent replicas of void space of natural rock fractures. This technique has been applied to a fracture specimen from Dixie Valley and theoretical predictions of two-phase relative permeability were made using the measured void space geometry. The predicted relative permeabilities show a strong anisotropy caused by the highly anisotropic spatial correlations among fracture apertures.

The field work includes microseismic monitoring of the Northwest Geysers and a proposed pressure-tracer test; both projects involve cooperation with industry. The microseismic monitoring network is currently collecting data and LBL will perform the processing and analysis of the data; the goal of the project is to determine locations of high permeability flow paths in the reservoir. The proposed pressure-tracer test is aimed towards evaluating the reservoir transmissivity and determining well-to-well hydrological connectivities.

Theoretical studies are being conducted primarily to evaluate the effects of reinjection on the reservoir pressure decline and enthalpies of producing wells. A cooperative study with the Philippine National Oil Company (PNOC) on Palinpinon has resulted in a comprehensive evaluation of chemical and thermal breakthrough at producing wells. These studies yielded detailed evaluation of fracture porosities, permeabilities and spacings which are the primary parameters controlling the movements of chemical and thermal fronts. This methodology will be applied to selected Geysers data sets to evaluate the dispersivities of the injected fluids and the resulting impact on the pressure decline. Additional studies include continued evaluation of permeability enhancement due to cold water injection and model improvements to provide state-of-the-art tools for the evaluation of The Geysers and other geothermal fields.

Programmatic R&D Objective: Reduce uncertainties related to long-term reservoir changes.

Potential Technologies/Innovations Expected: Improvements in modelling flow in multi-permeability reservoirs; improved seismic methods for monitoring fluid movement in reservoirs; better understanding of changes in chemistry during production.

Potential User Group(s): Geothermal developers, financiers, utilities.

Expected Time Frame for R&D Completion: FY-89 through FY-93

DOE HQ Program Manager: Marshall J. Reed

ADSORPTION IN VAPOR-DOMINATED SYSTEMS

**Henry J. Ramey, Jr.
Stanford University**

Vapor-dominated geothermal systems have been produced for almost 90 years. The largest geothermal power development in the world is The Geysers field in California near San Francisco. However, the fluid storage mechanism is still unknown despite the advanced stage of development of the important system. Recent events in production of this field indicate the importance of future planning for mature vapor-dominated systems. Analysis of performance of the original producing area at The Geysers indicates that desorption of adsorbed liquid may be a dominant storage mechanism at The Geysers. Results also indicate that the mass adsorbed in this part of the field is not a linear function of pressure. This finding may have a strong impact on attempts to model reservoir behavior, and planning reinjection strategies needed for future operations. Laboratory measurements of adsorption are required to assess the validity of field data analysis.

Programmatic R&D Objective: Reduce uncertainties related to long-term reservoir changes.

Potential Technologies/Innovations Expected: Improvements in modelling reservoir behavior and managing reinjection strategies.

Potential User Group(s): Geothermal developers, financiers, utilities.

Expected Time Frame for R&D Completion: FY90 through FY92

DOE HQ Program Manager: Marshall J. Reed

MANAGEMENT OF GEOTHERMAL RESOURCES

Dennis L. Nielson, Phillip M. Wright, Michael C. Adams,
Joseph N. Moore, and Alan C. Tripp
University of Utah Research Institute

Research at UURI concentrates on quantifying the processes taking place in geothermal systems and in developing methods to detect and monitor those systems. The past year's research has placed a greater emphasis on problems identified at The Geysers. As more geothermal systems reach a mature stage of production, production declines will become more common unless more effective resource management techniques are developed.

Work is progressing on the development of vapor-phase tracers, and we are planning a tracer test with several of the operators. Mineralogical and geochemical studies to determine the origin and distribution of corrosive steam are continuing in cooperation with GEO Operator and UNOCAL.

Hydrogeochemical studies using fluid-inclusion and chemical data are continuing at Coso, Steamboat, Heber and the Valles caldera. This work is documenting fluid flow in fractured geothermal systems and in changes in fluid chemistry caused by production.

Our investigation of the application of borehole geophysics has continued with the development of two different 2-dimensional inversion algorithms for interpretation of cross borehole and borehole-to-surface data. Instrumentation is being assembled to field test the method. We believe that these techniques can be effective in mapping permeable zones and reservoir boundaries. In addition, this method can be used to monitor the drying out of vapor-dominated reservoirs and cold water influx into liquid-dominated reservoirs.

Investigations of the state of stress in the Heber geothermal field suggest that borehole breakouts may be related to the proximity of major fracture zones. Concepts of stress have been used to develop a model for The Geysers system in which a structural arch effectively decouples the reservoir from the vertical stress. This model will be important in the planning of injection to control pressure declines.

Programmatic R&D Objective: Increase success rate of exploration wells. Improve siting of production wells. Reduce uncertainties of reservoir decline predictions. Improve methods of detecting and confirming reservoirs. Formulate models for fracture permeability. Develop understanding of reasons for pressure decline and generation of acid-steam in The Geysers and develop mitigation measures.

Potential Technologies/Innovations Expected: Liquid- and vapor-phase tracers for use in geothermal systems, stress modeling for injection management, geophysical methods to detect reservoir drying in The Geysers and permeable zones in liquid-dominated fields, new hydrogeochemical models of geothermal systems.

Potential User Group(s): Geothermal developers, utilities, independent power producers, direct-heat users.

Expected Time Frame for R&D Completion: Some technologies are available now on a preliminary basis; others will be available within 2-5 years.

DOE HQ Program Manager: Marshall J. Reed

**RESERVOIR RELATED RESEARCH AT
IDAHO NATIONAL ENGINEERING LABORATORY,
LAWRENCE LIVERMORE NATIONAL LABORATORY,
AND OAK RIDGE NATIONAL LABORATORY**

**J. L. Renner, INEL
P. W. Kasameyer, LLL
R. E. Mesmer, ORNL**

Idaho National Engineering Laboratory (INEL), Lawrence Livermore National Laboratory (LLL), and Oak Ridge National Laboratory (ORNL) conduct research in reservoir engineering, geophysics, and geochemistry, respectively, in support of the DOE Reservoir Technology Research Program. INEL's research has centered on the development of a reservoir simulation code to predict heat and solute transfer in fractured, porous media. The results of that development were reported to the geothermal industry in a technical transfer workshop during 1989. In support of the initiatives for research at The Geysers, INEL will initiate in cooperation with Lawrence Berkeley Laboratory, studies of injection and related interference effects at The Geysers. Work at LLL is centered on analysis of the seismicity associated with production and injection at geothermal systems and effects of geothermal systems on seismic signals. LLL is continuing studies of seismic attenuation related to the presence of steam at The Geysers. ORNL conducts research to obtain the thermodynamic and kinetic data needed as input into geochemical models such as those being developed by John Weare of the University of California, San Diego, that predict the phase behavior and corrosion characteristics of geothermal brines. The current program at ORNL addresses the ion interaction parameters of bisulfate ion (HSO_4^-) with H^+ and Na^+ , the dissociation constant of HSO_4^- and the solubility and specification of aluminum in the system $\text{H}^+ - \text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{OH}^-$. ORNL is initiating studies of the distribution of HCl in steam in support of the expanded research program at The Geysers.

INEL is also involved in several other activities in support of the development of geothermal resources. INEL acts as liaison between the Geothermal Technology Organization and DOE and provides contract support for initiation of joint research. INEL also participated with several other National Laboratories in the preparation of an analytical study of renewable resources in support of DOE's ongoing National Energy Strategy. As a result of this study, INEL is initiating a review of geothermal reserves.

Programmatic R&D Objective: Reduce uncertainties related to long-term reservoir changes.

Potential Technologies/Innovations Expected: Improvements in modelling flow in multi-permeability reservoirs; improved seismic methods for monitoring fluid movement in reservoirs; better understanding of changes in chemistry during production.

Potential User Group(s): Geothermal developers, financiers, utilities.

Expected Time Frame for R&D Completion: FY89 through FY92

DOE HQ Program Manager: Marshall J. Reed

OVERVIEW - HARD ROCK PENETRATION

James C. Dunn
Sandia National Laboratories

The Hard Rock Penetration program is developing technology to reduce the costs of drilling and completing geothermal wells. Current projects include: lost circulation control, rock penetration mechanics, instrumentation, and industry/DOE cost-shared projects of the Geothermal Drilling Organization. Last year, a number of accomplishments were achieved in each of these areas. Laboratory test equipment was designed and built to evaluate cementitious muds and polyurethane foams for lost circulation control in major fracture zones. Models for particulate plugging of loss zones were developed and used to summarize extensive laboratory data collected for a wide variety of material additives. Scale-model transmitting and receiving transducers were fabricated and tested for acoustical data transmission through drill pipe. Active noise and echo suppression was demonstrated and the drill pipe transmission concept was verified. Final testing of our prototype borehole directional radar was completed and an extensive redesign was initiated. The surface data acquisition system was completed for the GDO high-temperature borehole acoustic televiewer and logs were successfully obtained in the Salton Sea at temperatures up to 293°C. New drill pipe protectors that use a higher temperature elastomer were manufactured for geothermal applications and tested in The Geysers.

Programmatic R&D Objective: Reduce the cost of drilling and completing hydrothermal wells by 10 to 13 percent by 1992.

Potential Technologies Expected: Drilling technology, well completions, logging tools.

Potential User Group(s): Geothermal industry, drilling and logging industries.

Expected Time Frame for R&D Completion: Continuation of short-term projects.

DOE HQ Program Manager: Lew Pratsch

BOREHOLE DIRECTIONAL RADAR

Paul J. Hommert
Sandia National Laboratories

A directional radar tool is being developed for application in high resolution imaging of structure near a borehole. Previously, a prototype tool was constructed and tested in both laboratory and field environments. Targets in fractured media were successfully detected; however, the overall system dynamic range was found to be only about 40 dB. During FY89, work on the borehole radar focused on both mechanical and electrical redesign of the initial prototype. Also, in an effort to better define the operating characteristics that will be required of the eventual field system, a numerical model was developed that predicts the magnitude of reflected radar signals as a function of the host rock electrical properties and the fracture characteristics. Model studies indicate that a significant improvement in system dynamic range (40 to 60 dB) will be necessary for the borehole radar to be of practical use in locating fractures in most geothermal reservoirs. The electrical and mechanical modifications initiated in FY89 should achieve much of the needed improvement in dynamic range with changes in the antenna design achieving the remainder, and possibly more.

Programmatic R&D Objective: Decrease the cost of drilling production wells by 5% by 1992 through better identification of fractures.

Potential Technologies Expected: High-resolution imaging, reservoir characterization.

Potential User Group(s): Logging industry, geothermal, oil and gas industries.

Expected Time Frame for R&D Completion: 2 to 3 years

DOE HQ Program Manager: Lew Pratsch

LOST CIRCULATION TECHNOLOGY DEVELOPMENT PROGRAM PROJECTS

David A. Glowka
Sandia National Laboratories

Lost circulation is the phenomenon where drilling fluid is lost to fractures or pores in the rock formation rather than returning to the surface through the wellbore annulus. In geothermal drilling, lost circulation can be a serious problem that contributes greatly to the cost of the average geothermal well. A DOE-sponsored program is under way at Sandia National Laboratories to develop new technology for solving lost circulation problems. The Lost Circulation Technology Development Program currently consists of twelve projects in three areas: technology to plug matrix- and minor fracture-dominated loss zones; technology to plug major fracture-dominated loss zones; and technology to characterize loss zones.

Technology being pursued for matrix- and minor fracture-dominated loss zones includes development of high-temperature lost circulation materials (LCMs) and testing techniques, methods for emplacing them effectively, and analytical models to guide selection and emplacement of the LCM particles.

For major fracture-dominated loss zones, several downhole tools are being developed, including a drillable straddle packer, a porous packer, and a downhole injector. Studies are also being conducted in cooperation with Brookhaven National Laboratory to develop chemical formulations for converting bentonite drilling mud to a cementitious material useful in plugging loss zones.

In the area of lost circulation zone characterization, wellbore hydraulics models and borehole televiewer techniques are being developed to enable measurement of loss zone location, permeability, and pressure. This information is necessary to determine which type of treatment should be employed in any given case.

Programmatic R&D Objective: Development of Lost Circulation Technology to reduce geothermal drilling costs by 30% by 1994.

Potential Technologies/Innovations Expected: Several downhole tools, materials, and emplacement techniques for solving lost circulation problems.

Potential User Group(s): Geothermal drilling industry

Expected Time Frame for R&D Completion: FY 94

DOE HQ Program Manager: Lew Pratsch

**STATUS OF THE HOT DRY ROCK GEOTHERMAL ENERGY
DEVELOPMENT PROGRAM AT LOS ALAMOS**

David Duchane
Los Alamos National Laboratory

The Hot Dry Rock (HDR) Geothermal Energy Program at Los Alamos is directed toward demonstrating the viability of HDR as a practical energy source. Recently, a reservoir characterization experiment has been carried out to evaluate water loss, as a function of pressure and time, from the HDR Phase II Reservoir at Fenton Hill, N.M. This experiment has demonstrated that losses are small and decline with time and can be expected to be very small in a practical HDR system. In addition, programmatic advances have been made in reservoir engineering, seismic mapping, and tracer development. These advances have led to new concepts in HDR reservoir development and operation. All this work is leading up to an extended flow test of the Phase II reservoir. Preparations for this flow test include extensive engineering of the above-ground circulation loop to permit the test to be carried out safely, and in a manner which is technically sound and scientifically meaningful. This paper summarizes recent developments in all of the above areas.

Programmatic R&D Objective: Demonstration of the viability of energy extraction from hot dry rock.

Potential Technologies/Innovations Expected: Drilling and completion of deep wells into crystalline rock. High temperature downhole instrumentation. Reservoir analysis and modeling techniques. Seismic characterization technology.

Potential User Group(s): Energy developers and suppliers.

Expected Time Frame for R&D Completion: 5-10 years

DOE HQ Program Manager: James Rannels

USING HDR TECHNOLOGY TO RECHARGE THE GEYSERS

Donald W. Brown and Bruce A. Robinson
Los Alamos National Laboratory

As so succinctly pointed out by Bo Bodvarsson of LBL at the last GRC meeting, the main reason for the productivity decline at The Geysers is obvious: Much more fluid is being withdrawn from the reservoir than is being returned by reinjection and natural recharge. However, there is another factor that may be contributing to this decline -- the method of reinjection. By reinjecting condensate directly into the steam dome under hydrostatic pressure, as is the current practice, the significant pressure difference between the cold condensate and the hot, underpressured reservoir allows the reinjected fluid to fall rapidly to the bottom of the reservoir with very little residence time for heat transfer. This point is very important since the vast majority of the heat contained in The Geysers steam field is contained in the hot rock comprising the reservoir, and therefore a better means of heat transfer to the reinjected fluid needs to be considered.

It would appear that by using HDR-developed stimulation techniques, a more effective method of reinjection into The Geysers reservoir, to limit -- or possibly even reverse -- the observed productivity decline, could be developed. Pressurized injection of fluid, either from the boundary regions just outside the productive reservoir or from below the boiling interface, would be obvious approaches. These regions are under much higher earth stresses than the main body of the reservoir, providing a net inward flow potential towards the very subhydrostatic steam dome. However, no matter how thermally effective this method of artificial recharge might be, the amelioration of the decline still will be directly related to the amount of fluid available for reinjection relative to the overall mass rate of production.

Preliminary modeling results indicate that by using high-pressure stimulation techniques developed in the HDR Program, over two-thirds of the injected fluid will be flowing down gradient into the steam reservoir after only 20 days of peripheral reinjection at a rate of 53 kg/s (840 gpm). This fluid will start to flash as it approaches the reservoir through the pressure-stimulated network of joints in the rock immediately adjacent to the steam field, providing a hot recharge with a significant steam fraction. It is suggested that a series of tests to evaluate this HDR-based method of recharging The Geysers be conducted in cooperation with one or more of the major steam producers in the area.

Programmatic R&D Objective: To apply high-pressure stimulation and injection techniques -- developed in the HDR Program -- to mitigate the pressure decline at The Geysers.

Potential Technologies/Innovations Expected: A new method for enhancing the productivity and lifetime of existing hydrothermal reservoirs now being used for power production.

Potential User Group(s): Geothermal operators and independent power producers.

Expected Time Frame for R&D Completion: Mid 1990s, given adequate funding.

DOE HQ Program Manager: James Rannels

APPLICATION OF HDR TECHNOLOGY IN THE CLEARLAKE AREA, CALIFORNIA.

Kerry Burns
Los Alamos National Laboratory

The Clearlake project is an attempt to apply Hot Dry Rock (HDR) technology to energy production in The Geysers - Clearlake area, N. California.

A region of low permeability and conductive heat flow extends northeast of The Geysers over an area of about 40 x 15 km. The isotherms appear to form a broad, flat-topped ridge trending NE, cored by a line of young volcanic vents (0.1 my). The gradient averages about 100°C/km, higher in places. The host rocks are Franciscan greywacke, greenstone and chert. Well testing by the geothermal industry showed that the rocks are hot, brittle and impermeable, and respond favorably to hydraulic fracturing. The first artificial reservoir will probably be developed in Franciscan greywackes at a depth of about 8,000 ft and temperature of 250°C.

The HDR resource is relatively shallow and drilling to reach it should not be expensive. The gradient is comparable to some of the proposed Japanese commercial sites. The project hopes to take advantage of abandoned exploration wells to reduce costs even further. Construction of a reservoir by massive hydraulic fracturing is expected to be feasible. If plants were sited on a 2 x 2-km grid, there is space for over 100 producers, and several thousand megawatts of power production. There is also the possibility of high energy recovery by direct uses of low-grade heat, such as refinement of sewerage by heat treatment.

The resource is not, however, a homogeneous area of conductive heat flow. Within it are sporadic, fault-controlled hydrothermal plumes of deep-seated origin. These are hot and at low pressure. Development of numerous HDR plants, scattered throughout the region, will require finding, and either avoiding or managing, these plumes. On the southwest side, the HDR resource is bordered by the low-pressure steam field at The Geysers. Development near this border will require defining, and avoiding, or managing, interaction with the steam field.

Programmatic R&D Objective: The objective is to transfer technology from continental to Pacific Rim geothermal regimes, stress fields, and rock types. This will open up the world's greatest heat resource to HDR production methods. It will provide a new technology for export to a major group of less-developed countries.

Potential Technologies/Innovations Expected: The work will provide knowledge of a new regime of heat and mass flow, and experience in reservoir operations in this regime. In the future, it will lead to new technologies in management and operation of heterogeneous geothermal resources in an unitized fashion.

Potential User Group(s): Independent HDR well-field operators, working under agreement with city and county power and direct-use energy utilities.

Expected Time Frame for R&D Completion: About October 1992

DOE HQ Program Manager: James Rannels

GEOPRESSURED ENERGY - AN ENVIRONMENTALLY SAFE ALTERNATIVE

**Kenneth J. Taylor
Idaho Operations Office**

As a response to America's need for alternative energy sources, the United States Department of Energy has a Geothermal Program. Within this program is a category to study Geopressured Energy. Today many activities are taking place under the Geopressured Program. These activities for the most part fall under one of the following categories: Well Operations, Geoscience & Engineering Support and Energy Conversion. To date, this program has had many successes. However, there is still more information needed concerning the Geopressured Resource. It is thought that continued research will give the developer a better understanding of the Geopressured Resource and in turn increase the likelihood of its development.

Programmatic R&D Objective: Reduce cost of production from the Geopressured Resource to 6 to 10 cents/kWh.

Potential Technologies/Innovations Expected: Increased industrial development of the Geopressured Resource.

Potential User Group(s): Geopressured developers

Expected Time Frame for R&D Completion: 1993

DOE HQ Program Manager: Ray Fortuna and Raymond LaSala

THE GEOPRESSURED RESOURCE, RESEARCH, AND USE

Dr. J. Negus-de Wys
Idaho National Engineering Laboratory

The Geopressured-Geothermal Resource has an estimated accessible resource base of 5,700 quads of gas and 11,000 quads of thermal energy in the onshore Texas and Louisiana Gulf Coast area alone. After 15 years the program is now beginning a transition to commercialization. The program presently has three geopressured-geothermal wells in Texas and Louisiana. The Pleasant Bayou Well has a 1 MWe hybrid power system converting some gas and the thermal energy to electricity. The Gladys McCall Well produced over 27 MM bbls brine with 23 scf per bbl over 4½ years. It is now shut-in building up pressure. The deep Hulin Well has been cleaned out and short-term flow tested. It is on standby awaiting funds for long-term flow testing.

Supporting research on the Geopressured Program includes research at the University of Texas at Austin on rock mechanics, logging, geologic studies, reservoir modeling, and co-location of brine and heavy oil in Texas and California; at the Louisiana State University on environmental monitoring and geologic studies; and at the University of Southwestern Louisiana on hydrocarbons associated with the geopressured brines and development of a pH monitor for harsh environments. Recently, Lawrence Berkeley Laboratory has been added to the research support in prediction of reservoir behavior. EG&G Idaho, Inc. is developing feasibility studies in FY-1990 on four use areas: 1) Thermal Enhanced Oil Recovery, 2) Direct Use, 3) Hydraulic and Thermal Conversion, and 4) Use of Supercritical Processes and Pyrolysis in Detoxification. This ongoing research and well operations are preparing the way to commercialization of the Geopressured-Geothermal Resource.

In January 1990, an Industrial Consortium for the Utilization of the Geopressured-Geothermal Resource was convened at Rice University, Houston, TX. Sixty-five participants heard industry cost-shared proposals for using the hot geopressured brine. Proposals ranged from thermal enhanced oil recovery to aquaculture, conversion, and environmental clean up processes. By the September meeting at UTA-Balcones Research Center, industry-approved charters will have been received, an Advisory Board will be appointed, and election of officers from industry will be held. The 2-volume proceedings of the January meeting have been completed and display copies can be examined on the tables in the back of the room.

Programmatic R&D Objective: Development of technology and use of geopressured resource by 1995.

Potential Technologies/Innovations Expected: Cogeneration, conversion, direct use, in-line benzene monitor, pH monitor for GPGT, thermal enhanced oil recovery.

Potential User Group(s): More efficient/cost-effective conversion and energy use, industrial consortium.

Expected Time Frame for R&D Completion: Ongoing, resource available at Pleasant Bayou and Hulin wells.

DOE HQ Program Manager: Ray Fortuna

**ASSESSMENT OF GEOPRESSURED-GEOTHERMAL RESOURCES
FOR NEAR-TERM UTILIZATION**

C. G. Groat
Louisiana Geological Survey

There have been several assessments of the geopressured-geothermal resource base ranging from grandiose estimates of an almost boundless source of energy to very conservative forecasts tied to a very limited capability to produce only the methane component. Geologic studies and the test well programs supported by the Department of Energy have provided a better defined geologic framework for determining the true production potential of the thermal, kinetic, and dissolved methane components of the resource. New geophysical data is making it possible to complete the geologic analysis of the reservoirs at two of the designed test well sites which will aid in refining reservoir performance models. This should facilitate a more quantitative and accurate extrapolation of designed well test results to other reservoirs in the Gulf Coast area, thereby fostering realistic near-term resource utilization projections.

Production of geopressured brines at the Gladys McCall test well in coastal southwestern Louisiana had reached 27 million barrels when flow testing was discontinued in October 1987. Reservoir modeling has been somewhat hampered by a lack of detailed geologic data on reservoir extent, geometry, and textural variations. Only limited production has occurred at the Hulin site near Erath, Louisiana, where the deepest, hottest, and potentially largest geopressured reservoir system has been penetrated. The geologic understanding of this reservoir is also limited by the lack of other wells reaching to or beyond the depth of the reservoir of interest. Proprietary modern geophysical data from both areas are being used to more accurately portray the extent of the tested reservoirs and their relationship to other sand bodies.

Interest in the dissolved methane component has varied considerably during the period of DOE-supported investigations; during the period of highest natural gas prices in the early 1980's it far outreached interest in the geothermal energy. Given the increased emphasis being placed on natural gas in the development of energy strategies for the future, the estimated 5700 Tcf of speculative geopressured dissolved gas resources should be reassessed and data bases consolidated. This is necessary to bring our understanding of the geopressured gas resource onto a par with tight gas and unconventional gas resources that have received more attention in recent years.

Environmental monitoring at test well sites continues to demonstrate a lack of contemporaneous adverse subsidence, fault activation, and water quality impacts related to brine production and disposal. This good news should add to the appeal of the resource in a time of decreasing tolerance of energy-related adverse environmental impacts by the public.

Programmatic R&D Objective: Determination of production capabilities of geopressured reservoirs.

Potential Technologies/Innovations Expected: Effective reservoir models

Potential User Group(s): Energy production companies

Expected Time Frame for R&D Completion: Continuing through 1993

DOE HQ Program Manager: Ray Fortuna

GEOPRESSURED-GEOTHERMAL ENERGY FIELD OPERATIONS

B. A. Eaton, T. E. Meahl, and C. R. Featherston
Eaton Operating Company, Inc.

America's increasing dependence on foreign energy sources and the national environmental initiatives based on the increasing awareness of the need for protection of the environment have led to the Department of Energy's (DOE) development of domestic U.S. alternative energy programs.

One of these programs is the current geopressured-geothermal five-year program conducted at three sites in Louisiana and Texas. Excellent results have been obtained in reaching the objectives for this well operation and energy conversion project, which are:

- To determine geopressured-geothermal reservoir sizes and drive mechanisms by long-term, high-volume flow testing.
- Prove long-term injectability of large volumes of spent brine.
- Develop technology for automated operation of geopressured-geothermal production systems.
- Develop modified scale inhibitor treatment procedures.
- Develop technology to produce power economically from the geopressured-geothermal resource.

Programmatic R&D Objective: (See Above)

Potential Technologies/Innovations Expected: (See Above)

Potential User Group(s): Power companies, geothermal farming groups (crops, seafood, fish, etc.), breweries, desalinization plants, etc.

Expected Time Frame for R&D Completion: 10 Years

DOE HQ Program Manager: John E. Mock

**OPERATION OF A GEOPRESSURED HYBRID POWER
SYSTEM AT PLEASANT BAYOU**

Richard G. Campbell and Mai M. Hattar
The Ben Holt Co.

The U.S. Department of Energy and Electric Power Research Institute are cofunding a demonstration of the hybrid cycle power concept on a geopressured resource. The power plant was constructed at the Pleasant Bayou geopressured test facility in Texas and has been operational since August 1989. This paper presents an overview of the design and construction and a detailed discussion of plant operation and performance.

Programmatic R&D Objective: Develop technology to produce power economically from the geopressured resources.

Potential Technologies/Innovations Expected: The design and operation of a geopressured hybrid power system.

Potential User Group(s): Geopressured developers.

Expected Time Frame for R&D Completion: FY91

DOE HQ Program Manager: Raymond Lasala

OVERVIEW - MAGMA ENERGY

James C. Dunn
Sandia National Laboratories

A national energy strategy for the U.S. should include development of short, intermediate, and long-term resources. Crustal magma bodies located in the crust at shallow depth represent an enormous potential resource that deserves to be evaluated for development within the next 10 to 15 years. The estimate of the potential magma resource base in the U.S. is as high as 500,000 quads. This estimate is larger than our fossil resources and approximately 6500 times the total annual U.S. energy consumption.

Several years of DOE-supported R&D in magma energy extraction have changed the prevailing attitude about this concept from: "Of course there is a major magma resource, but it cannot be harnessed," to: "If there is a major body of magma at shallow depths, energy can be extracted." The engineering details are by no means all worked out. But, the important questions have been addressed and satisfactorily answered in a preliminary sense. This includes designing insulated drill pipe to extend drilling techniques used successfully in molten lava at Kilauea Iki lava lake to depths typical of crustal magma bodies. Materials research has identified and tested several common superalloys that will survive the expected energy extraction environment for several years. Extensive experimental and numerical analyses of energy extraction processes have resulted in projections of single well energy extraction rates of 25 to 45 MWe.

The primary unanswered question at this stage of development is: What is the nature of the crustal magma resource? (How deep? What volume? What thermal state?) These questions can only be answered by deep drilling into the magmatic regime. The Long Valley caldera deep exploratory well is designed as a beginning to address these important issues. Long Valley is a very large silicic caldera that best typifies the magma resource estimate. The well, located on the resurgent dome, will provide a stringent test of the hypothesis that magma is still present within the central plutonic complex of this active caldera.

Programmatic R&D Objective: Electricity production from a magma resource, on an experimental basis, by the year 2000.

Potential Technologies/Innovations Expected: High-temperature drilling technology, well completions, energy extraction, logging tools, and improvements in surface geophysics in volcanic terrain.

Potential User Group(s): Geothermal industry, electric utilities, drilling industry.

Expected Time Frame for R&D Completion: 10 to 15 years

DOE HQ Program Manager: Gladys Hooper

PHASE I DRILLING OPERATIONS FOR THE MAGMA ENERGY WELL

John T. Finger
Sandia National Laboratories

This paper describes the drilling operations for Phase I of the Magma Energy Exploratory Well in Long Valley caldera, near Mammoth Lakes, California. The hole is to be drilled in four yearly phases, with time for scientific experiments between the drilling intervals. Phase I was conducted during August - September, 1989, and resulted in a 20" cased hole to 2550 feet. Although the drilling encountered fractured zones with massive lost circulation, the hole is in excellent condition and is at the depth and diameter specified in the original design.

Programmatic R&D Objective: Electricity production from a magma energy source, on an experimental basis, by the year 2000.

Potential Technologies/Innovations Expected: Energy extraction, high-temperature drilling technology, high-temperature logging tools, high-temperature well completions, and improvement of surface geophysics.

Potential User Group(s): Geothermal industry, electric utilities, drilling industry.

Expected Time Frame for R&D Completion: On-going; completion of exploratory well will be followed by several years of scientific experimentation and monitoring.

DOE HQ Program Manager: Gladys Hooper

SILICIC MAGMA IN THE CRUST

John C. Eichelberger
Sandia National Laboratories

There can be no question that vast volumes of silicic magma exist today at numerous sites in the upper crust of the continents. The frozen remnants of such chambers, granitic plutons, have characteristic vertical and horizontal dimensions on the order of kilometers. Through tectonism sustained over tens of millions of years, such bodies accumulate in batholithic masses covering areas up to a hundred thousand square kilometers. These are a distinguishing structural and lithologic feature of continental crust. That the process of high-level emplacement of granitic magmas is ongoing is shown by numerous catastrophic outbursts in recent geologic time, with individual volumes on the North American continent of up to 1000 km³. The depth of these bodies varies greatly, but stratigraphic observations from plutons and the local subsidence that accompanies most large-volume eruptions show that a significant proportion of silicic diapirs penetrate to within a few kilometers of the surface; that is, to within reach by drilling.

Programmatic R&D Objective: Electricity production from a magma resource, on an experimental basis, by the year 2000.

Potential Technologies Expected: High-temperature drilling technology, well completions, energy extraction, logging tools, and improvements in surface geophysics in volcanic terrain.

Potential User Group(s): Geothermal industry, electric utilities, drilling industry.

Expected Time Frame for R&D Completion: 10 to 15 years

DOE HQ Program Manager: Gladys Hooper