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# GEOTHERMAL RESEARCH AND DEVELOPMENT ACTIVITIES OF THE U.S. DEPARTMENT OF ENERGY

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## KEYNOTE ADDRESS

Thank you. It's a pleasure to be here to address you on the geothermal R & D activities of the US Department of Energy. As you are probably aware, the last few years have brought substantial changes in the US Government's energy programs. This has resulted in a shift away from "commercialization" and a reduction in the geothermal R & D budget, consistent with the administration's policy of reducing interference in the free market and reducing Federal deficits.

As we look forward to fiscal year 1983, we will continue bringing demonstration programs to an orderly conclusion and redirect our emphasis toward critical high-risk R & D that industry is not expected to undertake. At the same time, our cooperation with industry through the Electric Power Research Institute, the Geothermal Resources Council, and our many other contacts will continue as we do our best to interpret industry's interests and policies to make sure that our program remains relevant.

An R & D review conducted for DOE last year concluded that Federal R & D on generation of electricity from geothermal resources has been too heavily funded in the past. It predicted that geothermal energy will have a low impact on national energy supply and stated that if a Federal geothermal program is continued, emphasis should be on low temperature process heat and the completion of the hot dry rock program; not on geopressured resource development, where the technical risk appears high, or on hydrothermal electric generation, where industry is capable of solving the remaining problems. These recommendations seem to have been only partially adopted. Our commitment to the already defined hot dry rock program has been reaffirmed, and the geopressure program will most likely be concluded this year. However, the direct heat program is being phased out, and hydrothermal research will continue.

Our strategy now is to support research that will result in a broad technology base for use by the private sector. We have shifted away from Federal sponsorship of power on line toward reliance on the private sector for commercialization and demonstration activities. Our new emphasis, therefore, is on basic energy science and technology on energy R & D of a long-term, high-risk nature.

Let me now discuss our specific geothermal R & D activities.

## HYDROTHERMAL TECHNOLOGY DEVELOPMENT

The objective of our hydrothermal research activities is to develop the technology base which will enable the geothermal industry to reduce the field development costs, the capital costs of electric generating facilities, and the technical risks of fluid handling, in order to expand the economically exploitable resource base by a factor of four or more. The R & D includes research on reservoir capacity and longevity, full-scale plant economics, and as yet unproven energy extraction and heat cycle technologies. Our program has addressed these issues by funding research activities in six technology areas:

Reservoir Stimulation - includes hydraulic fracture, explosive fracture, acid treatment, and propping techniques to improve well flow rates. Production rates many times those of oil and gas production are required for economic production of electricity from liquid-dominated hydrothermal resources. Stimulation techniques, materials, and equipment must be suitable for use in 300-600°F high salinity brine.

Under the program conducted by Los Alamos National Laboratory, several stimulation technologies have been developed and field tested with at least some success. A long column of a specially formulated HITEX explosive, safe until heated by downhole conditions, was detonated successfully in a poor producer at the Geysers, California. While it failed to cause much of an increase in flowrate, we regard the successful use of this explosive as an important accomplishment. Similarly, while the acid treatment of a well at Baca, New Mexico, did not make it a good producer in the long term, there was considerable flow enhancement at first, leading us to speculate that the eventual problem may have been due to improper production practices. Conventional hydrofracking and propping of a well at East Mesa, California, more than doubled the flow rate. Hydrofracking of a well at Raft River, Idaho, succeeded in yielding flow from a poor producer, but the fluid temperature was too low for the well to be of any significant value to us. We've had good luck with innovative proppants such as resin-coated sand and bauxite.

One more stimulation experiment is planned before conclusion of this program element.

Energy Conversion and Meat Cycle Research - involves advanced power plant hardware and thermodynamic cycles. The program continues to emphasize binary cycle conversion technology, consistent with the more prevalent moderate temperature hydrothermal resource base found in the US and the established commercial technology. We've paid particular attention to development of direct contact heat exchangers as a solution to the problems of fouling of heat exchangers in high salinity brines. A 500 kW direct contact pilot plant incorporating a spray tower heat exchanger has been built and tested at East Mesa, California, with excellent results in terms of immunity to chemical problems and very good pinch points. Recovery of working fluid from existing brine by means of flashing and vapor compression appears to be a quite reasonable approach. A sieve tray direct contact heat exchanger was tested on a 60 kW loop at Raft River also with good results. Remaining questions on direct contact heat exchanger technology include prediction of temperature profiles, process stability, flooding limits, and most importantly, economics relative to surface heat exchangers. It appears that by the time peripheral equipment is thrown in, there may not be much of a cost advantage to direct contact heat exchange, but it does work. We hope to wrap up our work on direct contact boilers this year and publish final reports on the results. Another important aspect of the program is development of reliable downhole brine pumps for flow enhancement and prevention of downhole flashing. Our goal is a pump that will deliver 1500 gpm at a sktting depth of 1500 ft continuously for one year at 375°F, and believe it or not, I think we'll make it within a year or two. Just recently we pulled an 80 HP pump from a 340°F well at East Mesa after nearly one year of operation. The motor appeared to show no sign of brine intrusion thanks to a positive pressurization system. We plan to extend the same technology to protect the cable and pothead as well. We also plan to do some work this year on selected improvements to the thermodynamic cycle itself. Currently a net geofluid effectiveness of about 8 watt-hours per pound for a 360°F resource is possible using a mixed isobutane-isopentane working fluid. We believe that by using more exotic fluids and a few tricks such as supercritical vaporization, recuperation, supersaturated expansion in the turbine, and evaporative dondensation, we can improve this to about 11 wh/lb. We are also sponsoring development of more accurate predictive models of the working fluids themselves at the National Bureau of Standards.

Finally, we are wrapping up research on a couple of total flow devices. Under the auspices of the IEA, we have been cooperating with Mexico, Italy, and New Zealand on evaluation of a Lysholm or helical screw expander. This device is presently being tested by the Ministry of Works and Development of New Zealand at Broadlands. Another total flow device called the rotary separator turbine is being tested at Roosevelt Hot Springs, Utah. While neither of these machines is yet perfected, they both run reasonably well on the total flow from a geothermal well and appear to have reasonably good conversion efficiencies.

Geochemical Engineering and Materials - research deals with fluid chemistry and characterization, geochemical monitoring and control of geofluids, and specification of materials for fluid handling and treatment. One of the highlights of this program has been the assistance we have provided to the privately developed 10 MW experimental binary cycle powerplant of Magma Power Company at East Mesa, California. This plant was extensively instrumented and monitored with DOE's help. High temperature sensors for carbon dioxide, and pH in brine, and probes to measure water, REDOX and particular levels in hydrocarbons have been developed. Some of these have been used by Magma to make valuable changes in plant design and operation. Beyond this, FLOCON, a carbonate scale inhibitor developed by Pfizer was tested successfully in the 500 kW direct contact pilot plant at East Mesa. A high temperature EPDM elastomer formulated by L'Garde for geothermal applications has been used successfully in packers in some of our hydrofracking experiments and in all the logging tools for the Fenton Hill hot dry rock project at temperatures of over 320°C. Seals made of NITINOL shape-memory alloy also have been used successfully. In Mexico, tests of high temperature polymer concrete as a well cementing material were conducted, and a large number of concrete pipe specimens have been exposed to geothermal conditions for prolonged periods with promising results.

In the coming year we plan to:

- design polymer concrete pressure vessels
- continue development of a model to predict formation of sulfide, carbonate, and silica scale
- study treatment of brine for reinjection
- investigate treatment of precipitate solid wastes
- investigate cathodic protection of well casings
- field test a high-temperature probe for measuring brine pH and
- continue work on high-temperature seals and bearings.

Environmental Control Technology - research has accomplished a great deal in the areas of injection monitoring and H S abatement. We have concluded that the EIC cuprosul copper sulfate scrubber is not economic or reliable enough for commercial application at this time; we have no further plans for investigation of this approach. The UOP catalytic oxidation process looks good for eventual comnercial use and is being tested by private companies. Incineration probably will play a major role in controlling emissions for existing units at the Geysers, and the Stretford process will be used on new units. Conversion of $H_2S$ to elemental sulfur by electron beam irradiation has been demonstrated in the laboratory but efficiencies are not yet high enough, and use of additives to improve the efficiency of this process is being considered. A direct chlorination process will be tested in Hawaii at the DOE Hawaii Geothermal Project.

Our program of injection monitoring for better reservoir management and protection of potable water aquifers will continue. Four geophysical techniques are being evaluated: geotomography, tidal response, microseismicity, and self potential. Using tidal response, researchers at Laurence Livermore National Laboratory were able to model the controlling faults of the Raft River geothermal system with very good correlation to geologic data.

Geoscience Technology - involves surface and subsurface geological and geophysical techniques to improve the success rate in geothermal exploration and reservoir engineering to predict reservoir performance.

At the Lawrence Berkeley Laboratory, new instrumentation has been developed (and tested) to assist in determining seismic and electrical characteristics of geothermal fields. ASP, an automatic seismic processor providing real-time in-field processing of microearthquake data, was developed. The EM-60 controlled source electromagnetic loop was refined and its transmitter power increased. Our five-year program of cooperative reservoir engineering research with Mexico in the Cerro Prieto field has been concluded but a new agreement is being negotiated. LBL will continue its numerical modelling of the heat and mass transport of geofluids and recharge waters in response to the present 180 MWe level of production at Cerro Prieto I. Heat extraction, circulation of fluids and formation of boiling zones will be studied. They are also continually improving their overall geologic-hydrologic model. Monitoring of near-surface temperature and salinity fronts using resistivity methods will continue.

In the area of injection research, generic studies of the response of fractured reservoirs using Baca, Raft River, and Krafla data will be performed. The relationship between chemical and thermal fronts will be studied by means of numerical models and tracer studies. Chemical kinetics will be added to existing heat and mass transport codes $CO_2/H_2O$ and multi-waters mixtures already having been incorporated into some numerical models.

You may be interested in a handbook on low-temperature reservoir engineering that has been published by the Idaho National Engineering Laboratory and the Lawrence Berkeley Laboratory. Designed as an overview for the non-reservoir engineer, it covers basic and applied theory, conceptual modelling, testing during drilling, geochemical applications, and reservoir monitoring.

There is also a lot of current interest in fracture modelling. Lawrence Berkeley Laboratory is in the process of trying to develop feasible methodology for modelling fractured reservoirs. Princeton University is also doing analytic modelling of flow thru fracture. Finally, I'll touch on the excellent work on reservoir engineering being conducted at Stanford University by Roland Horne and his colleagues; namely, tracer studies of reinjection at Roosevelt Hot Spring (and possibly Los Azufres); heat extractor modelling, well test analysis, and the Annual Stanford Reservoir Engineering Workshop. You can hear more on some of these topics from Roland this afternoon.

Well Drilling and Completion Technology covers development of advanced drill bits, downhole drill motor seals, borehole cements, lost circulation control, and well descaling techniques. Sandia Laboratory in Albuquerque has been responsible for this effort. A good deal of work has been done on design of drag bit cutters for drilling in hard rock. Materials such as polycrystalline diamond carbide (PDC) and niobium - or tantalum-cemented carbide have been evaluated with good results in a field test in the Imperial Valley; a Security PDC drill bit tested by Union Oil Co. drilled twice as fast as two roller cone bits.

Modelling of stress patterns and mud flows have also helped improve designs. Both a cavitating water jet (CAVIJET) drill bit and a PDC drill bit enhanced with cavitating jets have shown great promise, but their applicability is currently limited to depths of about 1500 feet because cavitation will not occur at vapor pressures of less than about *3000* psi. Sandia has constructed a lost circulation test facility simulating a geothermal bore, and this facility has been used to test a variety of material for lost circulation control, core damage assessment techniques, and mud aging. Low density, less expensive aqueous foam drilling fluids have been successfully tested (i.e. found to be stable) under geothermal drilling conditions. Laboratory studies of in situ conversion of clay-base drilling muds to cement is under way. Several downhole instrumentation projects have had good results. High-temperature tools for measurement of flow, temperature, and pressure have been developed. An acoustic borehole televiewer has been upgraded to operate at 275°C. Digital data transmission was added to increase the tool's resolution, and it has been used to inspect wells in the Hot Dry Rock project at Fenton Hill, NM. A wellbore inertial navigation system based on ballistic missile design has been successfully operated in a 7500 foot well in Nevada. We hope to develop a cement bond inspection tool in the coming year.

Geopressured Resources

The objective of the DOE Geopressure Geothermal Program is to determine the magnitude, availability and producibility of geopressured resources for recovery of methane, hydreulic and thermal energy. It does not deal with well drilling technology since we feel this is well enough known.

The program is now at a crucial stage. Four wells, three in Louisiana and one in Texas, have been drilled (together with necessary disposal wells) to depths in excess of 10,000 feet into permeable sandstone formations containing water at almost lithostatic pressures.

The technology for drilling, completing and producing such wells safely at high rates (up to 50,000 barrels per day) has been a major accomplishment of the program to date. Testing has been performed in three of these design wells and in thirteen "wells of opportunity" which are unsuccessful oil and gas wells in geopressured areas.

We have learned that geopressure reservoirs generally contain natural gas at the saturation value but also have higher salt content (and consequently lower gas content) than had been expected before the start of the program. The latter trend had reduced the expected recovery rate of natural gas to 20-30 cubic feet per barrel, and reduces the possibility of economic feasibility of energy recovery from geothermal geopressure reservoirs at this time.

The next step is to carry out multi-month flow tests of the four wells, principally to determine the way geopressure reservoirs change as they are depleted. Two of the four wells are connected to relatively small reservoirs, and some depletion data has already been obtained. However, we have yet to observe a decline in gas concentrations below saturation.

The other two wells, with large reservoirs, may require several years before significant change can be seen in performance. The current DOE operating plan calls for completion of federally funded geopressure studies by the end of February 1983. If the two larger wells can be shown to be effective natural gas producers, they will most likely be allowed to continue to flow.

Hot Dry Rock

DOE and its predecessor agencies have sponsored hot dry rock (HDR) research at Los Alamos National Laboratory (LANL) since 1971. Field operations are being conducted at Fenton Hill, New Mexico, on the edge of the Valles Caldera,

Hot dry rock is an energy source with tremendous potential. The technical problem lies with economic extraction of the resource. In "proof-of-concept" experiments (also called Phase I) LANL has successfully extracted up to 5 megawatts of thermal power for extended periods. Foreign support is directed at Phase II experiments at Fenton Hill which have a nominal thermal power rating of 35 megawatts.

Japan and West Germany are partners in the project along with the U.S. Our trilateral relationship is formalized in an IEA Agreement under which West Germany and Japan each contribute up to $2.5M per year to the Fenton Hill Project. DOE picks up the remainer (at least 50%) of the budget. Our partners are permitted to station up to six technical staff members at LANL for extended periods. The agreement runs for four years, terminating after February 1983. By the end of February 1982, West Germany and Japan will have contributed $7.5M each.

LANL is currently in the process of creating the enlarged, Phase II reservoir at Fenton Hill. The Phase II reservoir is to consist of multiple, parallel fractures connecting two deviated wells drilled in hot rock at depths of approximately 14,000 and 15,000 feet in granite rock at temperatures slightly above 300°C. The two holes are both at an angle of 35° from the vertical, one above the other. While rock fracturing has been successful, LANL has yet to establish a connection between the wells; fractures have propagated in an unexpected direction. As a result, operational and scheduling adjustments have had to be made, with concurrent budget impacts. The prospect of completing an interim HDR reservoir with 2-3 connecting fractures spaced about 50 meters apart appears excellent, but delays of at least 3 months in the project's schedule are assured. The current schedule calls for resumption of fracturing operations in mid-November 1982.

The USDOE is committed to meeting the key technical objectives of the Fenton Hill Project contained in the IEA Agreement, as modified. We foresee a multi-year effort assuming substantial German and Japanese contributions and technical support through completion of the project.

In February 1983 we hope to accomplish the following:

1) Preliminary fracturing between the EE-2 and EE-3 wells will be completed, and a flow test conducted to measure thermal drawdown. Cold water will be pumped down the deeper well and hot water returned from the shallow well to an air-cooled heat exchanger.

2) Work will begin on the Final Engineering Reservoir System, increasing the volume of the fracture system connecting EE-2 and EE-3.

Hydrothermal Industrialization

Geothermal commercialization programs were largely phased out in prior years, but Federal support to critical long-range projects was continued so that benefits to government and the industry would accrue from earlier investments.

5 MW Pilot Plant

The 5-megawatt electric pilot plant using a binary Rankine power cycle at Malta, Idaho (Raft River) was completed, operated and closed down. It provided valuable technical and economic data on reservoir performance and power cycle operating characteristics for a moderate-temperature (150°C) hydrothermal resource.

"2nd" 50 MWE Demonstration Power Plant

This is the single biggest project in our program right now.

The plant will use an isobutane/isopentane (90%/10%) binary power cycle and will be located at Heber, California, in the Imperial Valley, where the geothermal resources are of the "matrix permeability" type. DOE will fund 50% of the project cost, San Diego Gas and Electric 33%, the Electric Power Research Institute 10%, and other participants about 7%. SDG & E will operate the plant.

The objectives of the project are to (1) test binary conversion system technology at pilot scale, (2) test and document reservoir performance characteristics of a specific liquid-dominated hydrothermal reservoir, (3) test and document the validity of reservoir engineering estimates and of reservoir productivity (capability and longevity), (4) provide a basis for the financial community to estimate the risks and benefits associated with geothermal investiments, and (5) act as a "pathfinder" for the regulatory process and other legal and institutional aspects of geothermal development.

Heber is one of the best understood reservoirs in the United States. Fifteen exploratory wells from 5500 to 9700 feet have been drilled already. According to an evaluation by Chevron, the potential of the field is 500 MW for 30-35 years. EPRI has confirmed this assessment; however, we believe these are conservative assumptions.

As far as status is concerned, preliminary design review and technical drawings have been completed, a 100% design review is scheduled for March 1983, 10 of 11 piping and instrumentation diagrams have been completed with only the brine system remaining undone, site development construction drawings are complete, half of the major procurement packages have been completed and advertised, and the turbine contract has been awarded. Overall, the design is 65% complete.

The schedule calls for ground breaking in November 1982, final approval of the heat sales agreement sometime between December 1982 and February 1983, construction between February 1983 and October 1984, and mechanical completion in December 1984. The original schedule called for full power qualification in March 1985, test and evaluation beginning in March of 1987, and project completion in July 1987; however, these dates will slip approximately one year.

"1st" 50 MW Demonstration Power Plant

The 50 Megawatt flashed-steam demonstration power plant at Baca, New Mexico, was being cost-shared by DOE, Union Oil Co., and the Public Service Company of New Mexico, but the project has been terminated by mutual agreement. In spite of earlier indications of a good hydrothermal reservoir from initial well tests, subsequent wells proved to be such poor producers that the program was no longer considered viable.

Hawaii Geothermal Project

DOE's participation in the HGP-A 3 MW flashed-steam power plant project at Puna, Hawaii, has been concluded successfully. The plant is generally running well at close to design output, although some problems have been encountered with leaking steam bypass valves and the $H_2S$ control system.

Geothermal Test Facility

The DOE Geothermal Test Facility, which in years past operated in part as a facility to provide free test support to private experimenters, presently operates primarily as a test site for DOE experiments. However, a new Pump Test Facility has been constructed at the facility. It will be used to develop and verify downhole brine pump designs suitable for use on the Heber 50 MW demonstration power plant if necessary.

Direct Heat Applications

The objective of the direct heat applications program is to provide examples of non-electric used of the moderate-temperature geothermal resources that exist in 37 of the 50 United States.

The technology for directly using geothermal energy for space heating and process heat is well developed and economic, but potential users are often unfamiliar with geotheml energy and see the drilling and testing of an initial production well as an unknown risk.

DOE has sponsored and co-funded more than thirty non-electric geothermal projects including process heating, district heating, and, most recently, an alcohol production project. Most of these projects were initiated in 1978 and 1979. No new efforts to assist in this area were started last year, but existing cost-shared field experiments were continued and a user-coupled drilling program was concluded. DOE expects to complete analysis and documentation of these experiments to provide economic, construction and operating data and development case histories to prospective users.

Geothermal Loan Guaranty Program

Loan guaranties approved under this fund are intended to accelerate the development and utilization of geothermal energy. The program is expected to minimize the lender's risk, develop a financial service infrastructure, develop normal borrower-lender relationships, promote competition, and encourage new entrants into the geothermal market. Accomplishment of these objectives will help to meet the requirements of pertinent public laws and provide a stimulus for geothermal development by the public sector without additional Federal assistance.

At the beginning of the year the Geothermal Loan Guaranty Program had issued loan guaranties for five projects at different geothermal reservoirs, totalling $136 million. A decision was made in December 1981 to continue to process the pending loan guaranty applications, and potential follow-ons within the limits of the remaining loan guaranty authority stipulated by Congress. Of eleven applications pending at the time of the decision, two were later rejected for incompleteness, three are at the DOE Oakland office awaiting additional information, and six were reviewed by headquarters. Of these six, three were approved for negotiation (totalling $53.8 million), one is under review, one awaits additional information and one was withdrawn by the applicant. Two of the original five applicants have indicated that they may submit follow-up applications.

The task of monitoring and servicing the loan guaranties, to assure that the technical and other contractual commitments are met, continues at the field office and headquarters. The disbursement of loan funds at contractually specified milestones is subject to DOE review and approval as each project proceeds.

## Geothermal R & D in the Geoscience Program of the Office of Energy Research

The objective of the geoscience program is to develop a quantitative and predictive understanding of geological, geophysical and geochemical structures and processes in the earth, and thus to ensure an effective knowledge base for energy resource recognition, evaluation and utilization in an environmentally acceptable manner.

The prtnctpal activities of the program relating to geothermal energy include:

1) Geology, geophysics, and earth dynamics, including research into the properties of earth materials, rock flow, fracture and failure, earth movement and seismic effects, and the Continental Scientific Drilling Program.

2) Geochemistry, including studies of themchemical properties of geologic materials, static rock-water interactions, and geochemical migration, and

3) Energy resource definition, including reservoir dynamics and modeling; and magma energy resources.

These programs are conducted mostly in the National Laboratories, with additional studies at Universities. The "Magma Tap" program has been concluded with the successful drilling into magma and extraction of energy by introducing water.

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