GEOTHERMAL PILOT STUDY

NATO Committee on the Challenges of Modern Society

LBL-6869
CCMS-81

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FINAL REPORT: Creating An International Geothermal Energy Community

LAWRENCE BERKELEY LABORATORY • UNIVERSITY OF CALIFORNIA, BERKELEY

Prepared for U.S. Department of Energy under Contract W-7405-ENG-48

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Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy, $ 6.50 Domestic; $13.00 Foreign
Microfiche, $ 3.00 Domestic; $ 4.50 Foreign

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LBL-6869
CCMS-81
UC-66
TID-4500-R66

NATO COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY

GEOTHERMAL PILOT STUDY FINAL REPORT: CREATING AN INTERNATIONAL GEOTHERMAL ENERGY COMMUNITY

JUNE 1978

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PREFACE

This is the final report for the Geothermal Pilot Study established under the auspices of the NATO Committee on the Challenges of Modern Society. The objective of the CCMS Pilot Program is to apply existing research results to a given problem, transmit findings and recommendations to the member countries, and stimulate appropriate follow-up action. This task could not have been accomplished in the five substudies of the Geothermal Pilot Study without the cooperation and support of all the participants involved. In addition to many others whose efforts are reflected in this report, the international geothermal energy community at large owes a special vote of thanks to Sadrettin Alpan, Mineral Research and Exploration Institute (Turkey); Richard Bolton, Ministry of Works (New Zealand); John Garnish, Energy Technology Support Unit-Harwell (United Kingdom); Oskar Kappelmeyer, Geological Survey (Federal Republic of Germany); Karl Ragnars, National Energy Authority (Iceland); and Paul Sangnier, Délégation Générale à la Recherche Scientifique et Technique (France) for their leadership in bringing the CCMS Geothermal Pilot Study to a successful conclusion.

The editors wish to express their appreciation to Edwina Campbell, Kenneth Fulcher, F. Allen Harris, F. S. M. Hodsoll, John H. Howard, James T. Kuwada, Anders Lundberg, Leland Mink, Inja Paik, Sidney L. Phillips, and Morton C. Smith for their comments and suggestions in the preparation of the final report. Special credit is due Evelyn Rowe of the Division of Geothermal Energy for her editorial and production assistance. And the support of the staffs at the Division of Geothermal Energy, Department of Energy (DOE); Word Processing Branch, Office of Administrative Services (DOE); and Technical Information Department of the Lawrence Berkeley Laboratory is gratefully acknowledged.

James C. Bresee
Winifred W. S. Yen
John E. Metzler

I. INTRODUCTION

The Geothermal Pilot Study under the auspices of the Committee on the Challenges of Modern Society (CCMS) was established in 1973 to apply an action-oriented approach to international geothermal research and development, taking advantage of the established channels of governmental communication provided by the North Atlantic Treaty Organization (NATO). The Pilot Study was composed of five substudies which were identified as useful areas for international cooperation by a committee of geothermal experts from eleven countries. They included (1) Computer-Based Information Systems, (2) Direct Application of Geothermal Energy, (3) Reservoir Assessment, (4) Small Geothermal Power Plants and (5) Hot Dry Rock Concepts. The United States served as the pilot country* for the Geothermal Pilot Study, with Italy and Turkey as co-pilot countries. Since its inception, the Geothermal Pilot Study has also included the participation of geothermal experts from Canada, Egypt, El Salvador, the Federal Republic of Germany, France, Greece, Haiti, Iceland, Indonesia, Ireland, Japan, Kenya, Mexico, New Zealand, Nicaragua, Netherlands, Philippines, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and Yugoslavia.

All five substudies of the Geothermal Pilot Study have been completed. The United States will present the final report of the Geothermal Pilot Study and recommendations for future cooperation at the Fall 1979 Plenary Session. A conference in 1980 will review the progress of geothermal development in the participating countries. The proceedings of that conference will serve as a follow-up report for the Geothermal Pilot Study.

This is the final report of the Geothermal Pilot Study. It is organized in three parts, with appendices. Part I is this introduction. Part II is an Executive Summary of the Geothermal Pilot Study that highlights the considerations, objectives, program efforts, and recommendations of the overall study and individual substudies. Part III consists of Sections A-E, one for each of the substudies in the Geothermal Pilot Study.

Each substudy report in Part III is divided into five sections: (1) Introduction, (2) Objectives, (3) The Program, (4) Conclusions, and (5) Recommendations for International Action. The body of each substudy report is intended to present a profile of the technical investigations carried out in the substudy. The conclusions and recommendations sections provide a statement of findings for each of the technical investigations and define areas for future cooperative activities in geothermal development.

Appendix 1 is a record of participants for the major international conferences of the Geothermal Pilot Study, and a summary of geothermal development among the participating countries is provided in Appendix 2.

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*A description of the CCMS Pilot Country concept is provided on page 4 under the section "International Participation".

A more detailed description of U.S. programs relevant to the CCMS Geothermal Pilot Study is included in Appendix 3. These summaries are intended to support planning efforts for the 1980 Review Conference on International Geothermal Development and to acquaint participating countries with ongoing U.S. programs.

II. EXECUTIVE SUMMARY

INTRODUCTION

Geothermal energy resources are a short distance from every spot on earth. However, they only become practical where there are near-surface intrusions of magma or molten rock, or where there are crustal distortions. The heat flow from all sources is recoverable in either water reservoirs or rock formations. Occurrences of practical geothermal energy are numerous and scattered throughout the world; yet the resource is very little used today. The approximately 1,400 MWe of geothermal energy being produced in eleven countries represents less than 0.1 percent of the earth's total demand for electrical power (see Figure II-1), and is a much smaller percent of the earth's total potential. In addition, the potential for direct (nonelectric) use of geothermal heat in agricultural, industrial, and space heating applications has only been partially explored.

Underutilization of geothermal energy results from a lack of knowledge about the technical and economic feasibility of developing the resource. Because of the past availability of cheaper energy sources such as oil and gas, there has been little incentive to overcome the technical and resource assessment problems that might lead to reducing economic uncertainties. Furthermore, the economic and environmental tradeoffs between geothermal energy and alternate fuels are still poorly understood.

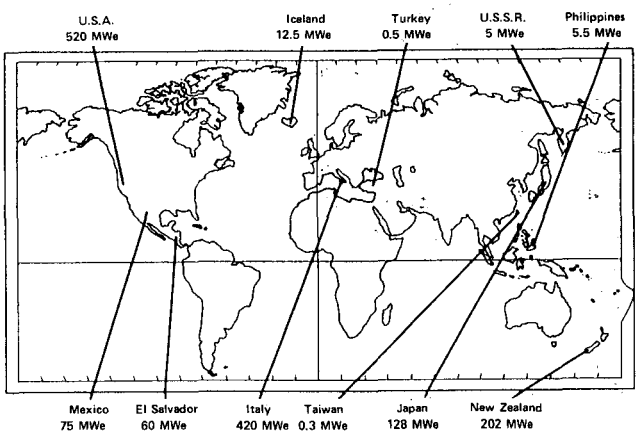

Figure II-1. Worldwide distribution of geothermal power (1400 MWe).

(XBL 785-8747)

The need for international cooperation to expand geothermal research and development was recognized by the United Nations well before the impact of the 1973 oil crisis. As early as 1961, participants at the United Nations Conference on New Sources of Energy made specific recommendations for cooperative research. During the decade 1965 to 1975, the United Nations executed several geothermal exploration projects in cooperation with the governments of El Salvador, Chile, Turkey, Ethiopia, Kenya, and Nicaragua. The first United Nations Conference on Geothermal Energy in 1970 further encouraged and supported international geothermal R&D activities.

CCMS

The NATO Committee on the Challenges of Modern Society (CCMS) was established in 1969 to address the concern of the industrial nations for the quality of life. Several features of CCMS have contributed to its effectiveness. One is an orientation towards short-term activities. Another is effective use of experts and resources on a given problem, emphasizing the synthesis of existing knowledge

toward practical applications as contrasted with basic research. The results of CCMS studies are disseminated to the public without any security or proprietary data restrictions. The liberal policy of accommodating outside observers in studies and meetings has fostered open communication among participants and the public at large. Finally, the effort to find long-term sponsorship for successful CCMS pilot studies has extended the impact of individual studies beyond their limited duration.

Geothermal Pilot Study

At the 1973 Spring Plenary held in Ottawa, Canada, the Honorable Russell Train, then United States Representative to CCMS, proposed that CCMS apply its action-oriented approach to solar and geothermal energy, resources that are viewed by many as less environmentally damaging than most present energy sources. Mr. Train stressed the urgency of the limited availability of fossil fuels, the resulting need to match energy supply to demand, and the necessity of improving the efficiency of energy use. These proposals received strong support from participants of the Plenary Conference.

Following the April 1973 Plenary meeting, the United States sponsored an international meeting of experts in California in October 1973 to draft a proposal for the Geothermal Pilot Study. The meeting included visits to geothermal sites in the United States and Mexico.

Five areas of useful cooperation were identified as relevant to the technical, economic, and institutional problems confronting geothermal development, and were subsequently approved by the CCMS Plenary Committee and the North Atlantic Council for the pilot study. These were (1) Computer-Based Information Systems, (2) Direct (Nonelectric) Uses of Geothermal Energy, (3) Multipurpose Processing and Disposal of Geothermal Brines, (4) Small Geothermal Power Plants, and (5) Hot Dry Rock Concepts. The third topic was subdivided for part of the project into Reservoir Engineering and Geothermal Fluid Injection and later recombined as Reservoir Assessment.

International Participation

The CCMS Geothermal Pilot Study made use of the "pilot country" approach, in which individual countries are responsible for coordinating the development and implementation of the studies, the preparation of the final project report, and the monitoring of recommendations in participating countries. The purpose of the "pilot country" approach is to avoid the creation of an international secretariat which may hamper direct interaction among experts. The viewpoints of those outside the Atlantic Community were available to help shape the Geothermal Pilot Study because the "silent consent" process permitted non-NATO countries to participate through the non-objection of member countries. Geothermal experts from non-NATO countries with a long history of geothermal experience, such as New Zealand, Mexico and Japan, played an important role in the substudies from the outset. As the individual substudies progressed,the participation of experts expanded to include nations not involved in the planning stages of the Pilot Study.

Fifteen countries accepted the general program proposals adopted by the organizing meeting in 1973 and appointed coordinators to arrange for national participation. A list of countries and respective coordinators is given below:

Canada	Alan M. Jessop
Federal Republic of Germany	Oskar Kappelmeyer, Richard Neumann
France	Paul Sangnier
Greece	P. Gounaris
Iceland	Karl Ragnars
Italy	Ezio Tongiorgi
Luxembourg	Emile Krieps
Mexico	Jorge Guiza
Netherlands	W. J. Elzinga
New Zealand	Frank Studt
Philippines	Arturo Alcaraz
Portugal	Alfredo Simoes Mendes
Turkey	Sadrettin Alpan
United Kingdom	John Garnish
United States	James C. Bresee

These fifteen countries, as well as many others not officially part of the CCMS Pilot Study, participated as observers or contributors in the substudy activities (Table II-1).

Individuals sometimes took part as private citizens, rather than with government sponsorship. In particular, Japanese geothermal experts always participated without government sponsorship and any implication otherwise is unintended. Management of the individual substudies was provided by the following persons:

Computer-Based Information Systems

Alan Clark, U. S. Geological Survey

Sidney Phillips, Lawrence Berkeley Laboratory (U.S.)

James Swanson, U.S. Geological Survey

Emilio Stefanelli, Centro Nazionale Universitario di Calcolo Elettronico (Italy)

Table II-1. Participation of international geothermal experts in the CCMS Geothermal Pilot Study (by substudies).

Nationality of Participants	Planning Meetings	Information Systems	Direct Applications	Injection	Small Power Plants	Dry Hot Rock
Canada	x		x			x
Egypt						x
El Salvador				x	x	
Federal Rep. of Germany	x		x	x	x	x
France	x		x	x	x	x
Greece	x		x			
Haiti					x	
Hungary			x			
Iceland	x		x		x	
Indonesia	x		x			x
Ireland			x			
Italy	x	x	x	x	x	x
Japan	x			x	x	
Kenya					x	
Mexico	x		x	x	x	
Netherlands			x			
New Zealand	x	x	x	x	x	x
Nicaragua			x		x	x
Philippines	x		x	x	x	
Portugal	x		x		x	
Spain			x			
Sweden						x
Switzerland			x			x
Turkey	x		x	x		x
United Kingdom			x		x	x
United States	x	x	x	x	x	x
Yugoslavia					x	

Direct Application of Geothermal Energy

John Howard, formerly Lawrence Livermore Laboratory, now Lawrence Berkeley Laboratory (U.S.)

Paul Sangnier, Délégation Générale à la Recherche Scientifique et Technique (France)

Reservoir Assessment

(a) Geothermal Fluid Injection

Kenneth Fulcher, U.S. Bureau of Reclamation

(b) Reservoir Engineering

Paul Kruger, Stanford University (U.S.)

Paul Witherspoon, Lawrence Berkeley Laboratory (U.S.)

Leland Mink, U.S. Department of Energy

Small Geothermal Power Plants

Anders Lundberg, Lawrence Livermore Laboratory (U.S.)

Hot Dry Rock

Morton Smith, Los Alamos Scientific Laboratory (U.S.)

Substudy Programs

The collaboration of many experts was instrumental in defining specific substudy objectives and developing implementation programs. The usual mode of operation was to convene a planning workshop during which the objectives of a substudy and an appropriate implementation program were identified. The entire Geothermal Pilot Study benefited from the First Implementation Conference held in New Zealand in May 1974, which reviewed the general status of international geothermal development and proposed possible ways of cooperation. A summary of individual substudy programs follows:

- The Computer-Based Information Systems Substudy, initiated at the New Zealand Conference, consisted of a one-year test of information exchange between computer centers in the United States and Italy. Subsequently, the information exchange system established under the test program was formalized in a bilateral agreement between the United States Department of Energy (formerly the Energy Research and Development Administration) and Consiglio Nazionale delle Ricerche (CNR) and Ente Nazionale dell' Energia Elettrica (ENEL) of Italy.

- The first phase of the Direct Application of Geothermal Energy Substudy involved the preparation of a summary report on the status of direct (nonelectric) uses of geothermal energy around the world. In the second phase, France, co-chairing the substudy, sponsored a Workshop on Space Heating in Paris in June 1976 and cooperated in an analysis of the value of geothermal energy for district heating and cooling. The substudy concluded in June 1977 in Washington, D.C., with a workshop on the Economic Aspects of Direct Application of Geothermal Energy.

- The Reservoir Assessment Substudy, which focused on reservoir engineering and geothermal fluid injection,

was initiated at the 1974 New Zealand Implementation Conference. Three subsequent workshops on the state of fluid injection technology were sponsored by New Zealand and the U. S. Bureau of Reclamation at Wairakei, New Zealand (December 1974), El Centro, California (May 1975), and Taupo, New Zealand (September 1976). The workshops were supplemented by visits to on-line geothermal installations, informal information meetings, and formal exchanges of information. As part of the reservoir engineering phase of the substudy, cooperation under the CCMS program provided a basis for discussions between the United States and Mexico which led to a joint program at Cerro Prieto, Mexico.

- The Small Geothermal Power Plant Substudy was co-chaired by the United States and Portugal. During Phase 1 of the substudy, a system concept for a small power plant was reviewed at two international conferences held in June 1975 at Berkeley, California, and the Azores, Portugal in September 1975. Phase 2 of the substudy involved the preparation of a set of technical guidelines designed to assist in the procurement and construction of a 5 MWe portable power plant.

- The Hot Dry Rock Concepts Substudy was intended to broaden the experience of experts in participating countries with hot dry rock potential. The substudy was carried out through a program of visits by foreign scientists to the U. S. Los Alamos Scientific Laboratory (LASL) in New Mexico and two international information meetings, held at LASL in September 1974 and July 1977.

The United States, as pilot country, reported semiannually at the CCMS Plenary meetings on the progress of each substudy, and presented an overview report of the CCMS Geothermal Pilot Study at the Second U. N. Symposium on the Development and Use of Geothermal Resources held in May 1975 in San Francisco, California. The International Energy Agency (IEA), which has assumed the lead in multilateral cooperation in geothermal energy, also held several informal reviews of the direction and progress of the CCMS Pilot Study in order to avoid duplication and ensure continuity where long-term programs were needed.

Summary of Accomplishments

The most significant overall result of the CCMS Geothermal Pilot Study has been the establishment of an identifiable community of geothermal experts in a dozen or more countries active in development programs. Membership in this community, although informal and changeable, is based on mutual respect and a mutual interest in cooperative research.

Specific accomplishments include the creation of an international computer file of technical information on geothermal wells and fields, the development of studies and reports on direct applications, geothermal fluid injection and small power plants, and the operation of the visiting scientist program. In the United States, the computer file has already proven useful in the development of reservoir models and of chemical geothermometers. The state-of-the-art report on direct uses of geothermal energy is proving to be a valuable resource document for laypersons and experts

in an area of increasing interest to many countries. Geothermal fluid injection studies in El Salvador, New Zealand and the United States have been assisted by the Reservoir Assessment Substudy and have led to long-range reservoir engineering studies in Mexico. At least seven small geothermal power plants are in use or have been planned for construction around the world since the Small Power Plant Substudy was instituted--at least partial credit for this increased application can be assigned to the CCMS Geothermal Pilot Study. Finally, the visiting scientist program at Los Alamos Scientific Laboratory (LASL) has contributed to European interest and stimulated parallel investigation in hot dry rock technology.*

These accomplishments represent only a partial list of contributions made by the Pilot Study to international cooperation in geothermal development. Equally significant are the plans for bilateral or multilateral programs to ensure the continuity of the research paths mapped by the five substudies. The substudies on Computer-Based Information Systems, Reservoir Assessment, and Hot Dry Rock concepts will continue under specific international agreements, while the substudies on Direct Applications of Geothermal Energy and Small Power Plants are under active review by the International Energy Agency.

Multilateral cooperation under the auspices of CCMS has influenced the direction of geothermal research and development programs throughout the world: Appendices 2 and 3 summarize the status of geothermal development in participating countries and selected U.S. programs relevant to the Geothermal Pilot Study. It is sufficient here to cite two examples of possible impact on national programs resulting from the Geothermal Pilot Study. First, the U.S. presidential budget for Hot Dry Rock Program studies in fiscal year 1979 is approximately double that for fiscal year 1978, partially in recognition of worldwide interest in the development of this technology--an interest enhanced by the CCMS program. Second, recent West German geothermal efforts have concentrated on the possible economic use of hot dry rock; West German scientists have made greatest use of the LASL visiting scientist program, and cooperation under CCMS probably played a role in their program emphasis.

Recommendations for Future Cooperative Activities

Highlights of the key recommendations which emerged from the five programs are as follows:

- The computer-based information system now operating should be used as the continuing medium for international exchange of geothermal information. The low cost and speed of the system offers much incentive for its use.

- In keeping with a general trend toward cogeneration, direct use of geothermal heat can be strengthened by emphasizing the cascade principle; that is, where geothermal electric power generation produces large quantities of low grade waste heat, there should be careful planning to use such heat for space heating, industrial processing, or agriculture. Such applications can improve overall economics

*"Hot dry rock" is often referred to as "man-made geothermal energy systems."

and contribute toward national energy conservation goals.

- The U.S.-Mexico technical program to study the Cerro Prieto geothermal reservoir in detail is well under way. Many of the methods used in the evaluation of the Cerro Prieto system are applicable to the evaluation of geothermal prospects throughout the world and can be strongly recommended for that purpose. This would contribute both to the global geothermal resource assessment effort and to the refinement of existing knowledge of reservoir characteristics.

- With international acceptance of conventional small-scale geothermal power plants as useful systems for early geothermal development, attention should be directed to advanced concepts. An example of an advanced system is the helical screw expander which would permit the use of wellhead generators where the type of geothermal fluid presently discourages the use of conventional flash-steam systems. Continuity in this regard is expected from an IEA project currently being planned.

- Finally, in the area of hot dry rock, much more can be accomplished if close links are maintained among the projects under way in the Federal Republic of Germany, Japan, Switzerland, Sweden, the United Kingdom and the United States. An opportunity for multilateral cooperation is provided by the IEA Project on Man-Made Geothermal Energy Systems (MAGES).

To review progress of geothermal development among participating countries, a follow-up review conference is planned in Paris in June 1980. The proceedings of that meeting will mark the official end of the Geothermal Pilot Project.

The NATO-CCMS Geothermal Pilot Study is drawing to a close with the completion of the substudies, but the process of cooperation it began and the technical progress it produced are continuing under longer-term bilateral and multilateral agreements.

III. SUBSTUDY REPORTS

A. COMPUTER-BASED INFORMATION SYSTEMS SUBSTUDY

INTRODUCTION

The immediate need for domestic energy resources has prompted some nations with geothermal energy potential to accelerate their efforts to develop this source. These efforts, which include resource assessment, well drilling, plant construction and maintenance, and analysis of environmental impacts, have resulted in an enormously increased volume of geothermal data. The data are widely scattered, difficult to access, and largely unevaluated.

It is within this context that the Computer-Based Information Systems Substudy was established at the First Geothermal Implementation Conference in New Zealand to investigate the use of computer data centers and to provide the benefits of worldwide data collection, evaluation, and exchange of geothermal energy information to participating countries.

OBJECTIVES

The Information Exchange Substudy was designed as a one-year study of two linked regional computer centers, to develop ways of acquiring and transmitting information so that the prompt exchange and dissemination of new information and data related to geothermal energy would be assured. Computers were used because they provided the most rapid, efficient, and economic means of handling large quantities of data. All information generated in one center would be transmitted to the other center and each would have a complete data file of all available information. Individual requests for specific information could be made to either regional center, and each center would provide information in appropriate tabular, graphic, or computer-readable formats.

Design of Substudy

Three linked regional information centers had been originally proposed at the New Zealand Implementation Conference. Suggested locations for the centers were Italy, New Zealand, and the United States, responsible for the collection of geothermal data from Europe, Asia, and the Americas respectively. Final implementation of the Information Exchange Substudy involved two computerized data centers, in Italy and the United States; New Zealand also took part in developing formats and in providing data. The intention of the participants was to exchange bibliographic and numerical data on a one-year trial basis to assess the time, cost, and usefulness of the work (Reference 1).

THE PROGRAM

Implementation of the program involved the following data centers: (1) Centro Nazionale Universitario di Calcolo Elettronico (CNUCE),*

*CNUCE began its life on July 5, 1965, as the "Centro Nazionale Universitario di Calcolo Elettronico" of the University of Pisa. Since November 1, 1975,

University of Pisa, Italy; (2) the National Geothermal Information Resource (GRID), Lawrence Berkeley Laboratory, Berkeley, California, and (3) GEOTHERM, United States Geological Survey, Reston, Virginia (now Menlo Park, California). A description of GRID and GEOTHERM is contained in Appendix 3-A. Specific tasks for the one-year pilot study included the following:

1. Collect bibliographic data on the following aspects of geothermal energy development, including information from other fields with relevance to geothermal energy: (1) Subsidence, (2) Hydrogen Sulfide, (3) Geothermal Resources, and (4) Direct (Nonelectric) Applications. Indexed and annotated bibliographic listings were made available either as computer printouts or magnetic tapes.

2. Tape site-dependent numerical data in the following subject areas: Geothermal Field/Area, Chemical Analysis, Geothermal Well/Drillhole.

3. Develop formats based on internationally accepted standards by CNUCE, GEOTHERM and GRID. See, for example, Reference 2.

4. Transmit computer tapes and other data files by diplomatic pouch.

The working committee for this substudy met in Menlo Park, Berkeley, Reston, Pisa, Wellington, and San Francisco during 1974 and 1975. Goals and objectives were established at meetings by key technical and scientific personnel, and the initial work plan was kept flexible to allow for changes in the tasks.

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it has become an Institute affiliated with the Committee for the Engineering and Architectural Sciences of the National Research Council.

The foundation of CNUCE took place within the framework of a conspicuous activity in the computing field which was already under way at Pisa. In the mid-1950's, following the suggestions which had been given by Enrico Fermi concerning the advisability and advantages of directing a part of the research work of the University of Pisa towards the computing sector, a group of researchers from the University designed and produced an electronic computer for the first time in Europe, the CEP (Calcolatrice Elettronica Pisana).

The research group consequently brought into being the "Centro di Calcolatrici Elettroniche" of the University of Pisa which has become the "Instituto per l'Elaborazione del' Informazione" (IEI) of the CNR. It should, however, be stressed that the position which Pisa holds in the field of informatics is due not only to the presence of CNUCE but also to that of the institutes for scientific research: the already-mentioned IEI of the University, the Clinical Physiology Laboratory of the CNR, etc.

Within CNUCE two fundamental, mutually integrated components co-exist: the data processing service in its various aspects of planning, organization and maintenance, and the research activity directed both at optimizing the service and at carrying out and participating in various projects in applied informatics.

The participants in these meetings included representatives from Italy, Mexico, New Zealand and the United States; generally, designated personnel from the predecessor agencies of the U.S. Department of Energy (the Atomic Energy Commission and the Energy Research and Development Administration) and United States Geological Survey (USGS) were also present. Because of the distances involved, it was not possible for all committee members to meet at each location. To coordinate and facilitate the acquisition of on-site data, A. Clark (GEOTHERM) and S. Phillips (GRID) made visits to Pisa and Wellington.

The results of the pilot study were reported at the Second U. N. Symposium in San Francisco, May 26, 1975 at a special afternoon session (Reference 3). The achievements of the trial study conducted by the U.S. and Italian data centers included:

1. Development of a common format for recording bibliographic information. The format had as its basis the International Nuclear Information System (INIS) descriptive cataloging procedures, indexing rules, and authority lists.

2. Development of a format for site-dependent numerical data for fields, drill holes, and chemical analysis. The format was based in part on the system used by the U.S. Geological Survey Office of Resource Analysis; it was reviewed by the New Zealand Department of Scientific and Industrial Research (DSIR) and included changes suggested by their staff.

3. A pilot bibliographic file by GRID and a pilot numerical file by GEOTHERM.

4. Establishment of a mechanism for tape exchange between the United States and Italy via diplomatic pouch.

5. Identification of problems in the exchange of geothermal energy data on an international basis among the three data centers (CNUCE, GRID, GEOTHERM).

All participants at the United Nations meeting agreed that the data exchange program should continue, and a draft document defining the scope of follow-up activities to continue the worldwide geothermal data collection was prepared by the Working Committee (Reference 3). The current status of an expanded effort in geothermal information exchange is discussed in the following section on the U.S.-Italy bilateral information exchange agreement.

In the United States the Computer-Based Information Systems Substudy has assisted geothermal research and development in the United States in a number of ways, including the development of reservoir models and of chemical geothermometers (Reference 4).

U.S.-ITALY BILATERAL AGREEMENT

In 1976, the geothermal information exchange system established under the one-year CCMS test program was formalized in a bilateral agreement between the United States Energy Research and Development Administration and Consiglio Nazionale delle Ricerche Geotermiche (CNR) and Ente Nazionale dell'Energia Elettrica (ENEL) of Italy. Under the bilateral agreement, the United States is responsible for data collection from Iceland, North America, Central America, South America, Australia, and Asia (except the USSR). Italy is responsible for data collection

from Europe (except Iceland), Africa and the USSR.

There are currently three U.S. data centers engaged in the collection and exchange of information on geothermal energy research and production: the DOE Technical Information Center (TIC), Oak Ridge, Tennessee; the GEOTHERM project of the U.S. Geological Survey in Menlo Park, California; and the GRID project at Lawrence Berkeley Laboratory in Berkeley, California. The data systems of TIC, GEOTHERM and GRID are coordinated for data collection and dissemination, with GRID serving as a clearinghouse; GRID interfaces with DOE/TIC for bibliographic information and with the U.S. Geological Survey for certain site-dependent numerical data. GRID also coordinates the collection of numerical data with the National Standard Reference Data System and other institutions.

GRID informally provided Pisa with a file on subsidence under the CCMS test program in July 1975; in 1976 more extensive computer tapes were sent to Pisa under the formal bilateral exchange agreement. These included the GRID hydrogen sulfide file; a tape from TIC, Oak Ridge, containing their geothermal bibliographic file; the GRID geothermal thesaurus; the EDB (Energy Data Base) magnetic tape description; and a description of the GRID document file structure. In June 1977, the following additional computer tapes were transmitted to Italy: the GRID geothermal hot water fluid data, the current TIC file on bibliographic data, and a composite file of geothermal energy abstracts from 1976 to 1977 from TIC. In December 1977, CNR transmitted to TIC and GRID a tape and printout of a portion of the PISA geothermal bibliographic file.

In October 1976, F. A. Harris (U.S. Environmental Protection Agency) described the U.S./CCMS Geothermal Information Program at a geothermal conference in Guatemala (Reference 5). This led to informal contacts with Central and South American geothermal specialists. Since 1977, GRID has continued this effort by working with the appropriate overseas embassies and the Department of State to establish mechanisms for the exchange of geothermal data among the United States and Central and South American countries.

CONCLUSIONS

1. The CCMS information exchange substudy and the follow-up work under the U.S.-Italian bilateral agreement have expedited the exchange of geothermal information worldwide and demonstrated the advantages of computerized information systems for such operations.

2. The success of such information exchange systems is dependent upon the cooperation and coordination of correspondent agencies in each participating nation. The principal difficulty is not design of the data system, but rather the mechanics of securing the information. Most participants are willing to contribute to the file, but the tedious and sometimes formidable task of coding forms for the computer has slowed down exchange of information.

RECOMMENDATIONS

The primary objective of the CCMS Substudy on Computer-Based Information Systems was to create an international geothermal energy data base, a pool of information from which all countries may draw. It is recommended that the computer-based

information system be used as the major medium of information exchange during the interval between major geothermal conferences. Supporting recommendations to facilitate the international exchange of information fall into two groups:

1. Tasks for Participating Countries

   a. Participating countries should continue to collect copies of material for transmittal to the designated computer centers. Each country should establish its own priorities for the acquisition of data, but emphasis should be placed on material which is not widely circulated or is difficult to obtain.

   b. A procedure for computer input should be established for transcribing the data on forms. Three alternatives have been suggested:

      (1) Those countries able to encode should do so.

      (2) The data could be copies of original data which would be sent to the data center for encoding.

      (3) Countries unable to encode might request assistance from those that can.

   c. The time required to exchange or transmit material between participating countries needs to be shortened, and participants should agree on the frequency (e.g., yearly intervals) of site visits by computer center staff to collect reports.

2. Tasks for Regional Data Centers

   a. The data centers should provide each participating country with data to meet its particular needs, coordinating requests for information with other organizations if necessary. In addition, a regular system for disseminating information should be organized, perhaps by means of a newsletter and periodic topical reviews of the file.

   b. Each center should contain both data evaluated by the center itself and data evaluated by others. Since there is insufficient time for the center to evaluate all information, sources of data should be identified.

   c. The data centers responsible for maintaining the computer tapes must increasingly be responsible for coding the inputs in the proper format. The computer centers will need adequate staffs to code the information.

   d. Large quantities of data are handled most effectively by computer; it is therefore necessary that developing nations now lacking computer capability gain expertise if they wish to make best use of geothermal data bases. The regional centers should provide this capability where it is needed and assist developing nations in acquiring their own capability.

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B. DIRECT APPLICATIONS OF GEOTHERMAL ENERGY SUBSTUDY

INTRODUCTION

Low to moderate temperature geothermal resources (<150°C) are found in many parts of the world, and they have been used for direct (nonelectric) applications since classical antiquity. In almost all cases, direct application in space heating, agriculture, and industrial processes is thermodynamically a more efficient use of geothermal fluids than converting the resource to electrical energy. Certain countries, notably Hungary, Iceland, and New Zealand, already use significant quantities of geothermal energy in direct applications, replacing the use of scarce and costly fossil fuels. However, the potential for direct application of geothermal resources around the world has only been partially explored.

The Substudy on Direct Application of Geothermal Energy was a first step in identifying and developing the technology needed for the direct use of geothermal energy. The main object of the substudy was to explore the economic and technical feasibility of using low-to-moderate temperature geothermal resources as a substitute for fossil fuels in space heating and cooling, industrial process heat, and agricultural uses in place of fossil fuels. The substudy also provided opportunities for international geothermal experts to share their experiences with direct uses and to define further directions for research in their domestic programs.

The study was conducted in two phases. The first phase of the study, under the leadership of J. H. Howard of Lawrence Livermore Laboratory, was concerned with examining the state of the art of direct applications and documenting the technological, economic, and institutional aspects of using geothermal resources for nonelectric purposes. A report entitled "Present Status and Future Prospects for Nonelectrical Uses of Geothermal Resources" (Reference 1), edited by Howard, concluded Phase I. The second phase, under the leadership of P. Sangnier of France, was concerned primarily with the economic aspects of direct uses of geothermal resources. Two international meetings were held under this phase:

1. C.D.S.M. Étude Pilote Géothermie, Paris, France, June 9-10, 1976, and

2. NATO-CCMS Conference on the Economics of Direct Uses of Geothermal Energy, Washington, D.C., June 21-22, 1977.

One report, "Geothermal Energy: Residential Space Heating" (Reference 3) has been issued. The proceedings of the Washington meeting are in preparation. Twelve nations participated in Phase I and eighteen in Phase II of the study.

OBJECTIVES

The first objective of the project was to report on the state of the art of direct application of geothermal energy. The report was intended to clarify the principles of application, identify technical and economic problems, and define the worldwide geothermal community

involved with direct applications. It was believed that such a report would spark further interest in direct applications and encourage the development of appropriate hardware.

At the completion of the status report, it became clear that the main obstacle to direct applications was not lack of technical knowledge, but uncertainty about how much it would cost. The objective of Phase II, therefore, was to resolve some of this uncertainty by analysis of present and future energy costs associated with operating systems.

THE PROGRAM

Phase I

In 1974, a number of countries endowed with geothermal resources had made significant progress toward using these resources for space heating and cooling, industrial process heat, and agriculture. New Zealand was successfully using geothermal resources for wood products processing, sulphur recovery, alfalfa drying, and paper milling. Over 50 percent of homes in Iceland were being heated by geothermal energy. The French space heating project in new towns in the Paris Basin had been initiated. In Italy, in addition to the better-known electric power production, geothermal energy was being used to heat greenhouses, offices, public buildings and homes. The Philippines, Turkey and Mexico also reported successes in direct applications of geothermal resources.

In the light of the interest in direct applications around the world, the members of the Geothermal Pilot Study felt there was a need to document and disseminate the technical, economic and other relevant information to encourage further development and application of low-temperature geothermal resources. Consequently, in April 1974, representatives from Canada, West Germany, France, Italy, Mexico, New Zealand, Turkey and the United States met in New Zealand to discuss preliminary plans for compiling a report on direct applications of geothermal resources. Following the meeting, several members of the group toured geothermal projects in France, Italy, and Iceland. The outline for the status report was developed in a 1974 meeting of international experts in Iceland.

A draft report, "Present Status and Future Prospects for Nonelectrical Uses of Geothermal Resources," was issued in April 1975, and comments on it were discussed at the time of the Second United Nations Geothermal Symposium. It was organized under four major headings: systems development, applications, economic and regulatory considerations. A brief summary of the report is presented below. The final report was published in October 1975 (Reference 1) and includes contributions from twelve nations. It remains one of the most useful documents on the subject of direct applications of energy.

Systems Development

The report surveyed existing geothermal resource exploration techniques and discussed problems associated with resource extraction and development. Environmental problems, including waste fluid disposal, were also considered. Contributing experts pointed out that direct applications of geothermal energy may be found for fluids as low as 20°C (See Figure III.B-1). However, geothermal energy is not always as inexpensive as many have assumed; in planning any project, the cost effectiveness of specific applications must always be compared with that of other sources of energy.

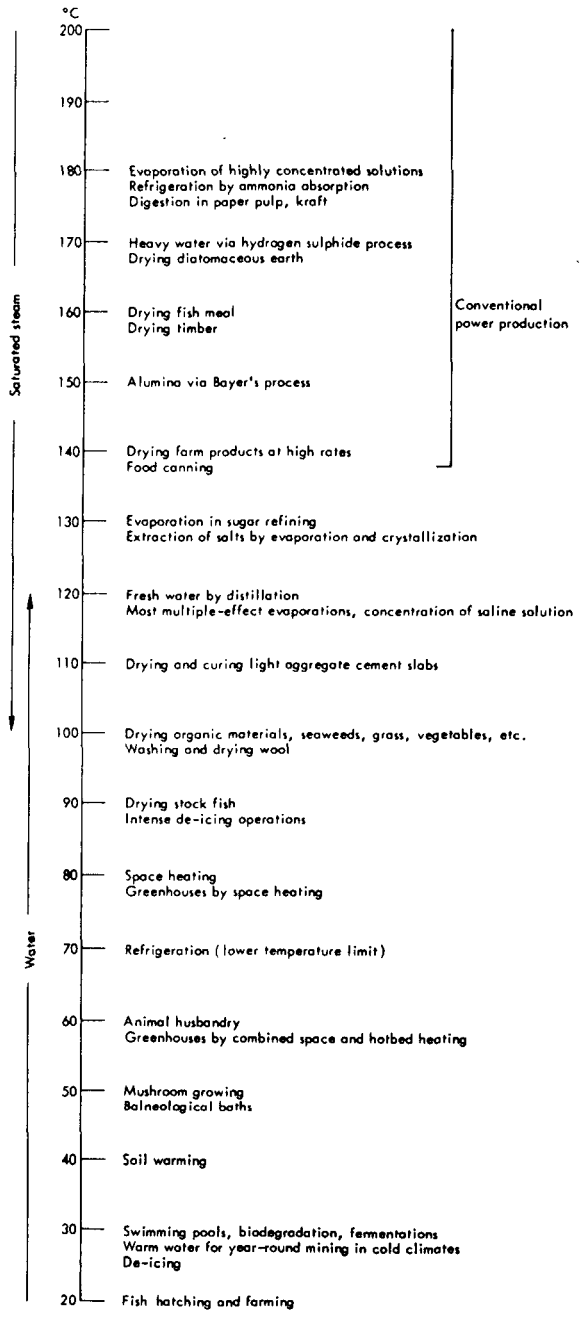

Figure III.B-1. Required temperature (approximate) of geothermal fluids for various applications (after Lindal, Ref. 2). (XBL 785-8732)

Applications

The section on applications reviewed residential, commercial, agricultural, and industrial uses. In 1975 residential and commercial space heating and cooling from geothermal heat amounted to 400 thermal MW. The report described two categories of space heating systems: district heating systems, such as the systems in Reykjavik, Iceland, and individual home heating such as Rotorua, New Zealand and Klamath Falls, Oregon.

Geothermal energy can be used to assist in the production of large amounts of food efficiently and cheaply. Research in agricultural applications is based upon earlier efforts on the use of waste heat from fossil fuel and nuclear power plants. The three most common applications are greenhouse heating (see Figure III.B-2), animal husbandry, and aquaculture. As much as 5,000-5,500 MW of geothermal power are being used for these purposes. Integrated geothermal greenhouse, agriculture and stock farm systems have been designed with the optimum temperatures for plant and animal growth in mind.

Although the number of geothermal industrial application projects is small, the power used in each is on the order of about 150-200 thermal MW, and encompasses a wide range of uses. The two largest operations using geothermal energy for process heat are a diatomaceous earth plant in Iceland and a pulp, paper and wood processing plant in New Zealand. Their experience illustrates the lead time and problems encountered in development of major projects.

Economic and Regulatory Considerations

Geothermal energy is often regulated by government just as fossil fuels, minerals, and water are. There are many laws affecting geothermal energy at all levels of government, and often they are confusing or contradictory. The report reviewed the institutional factors affecting geo-

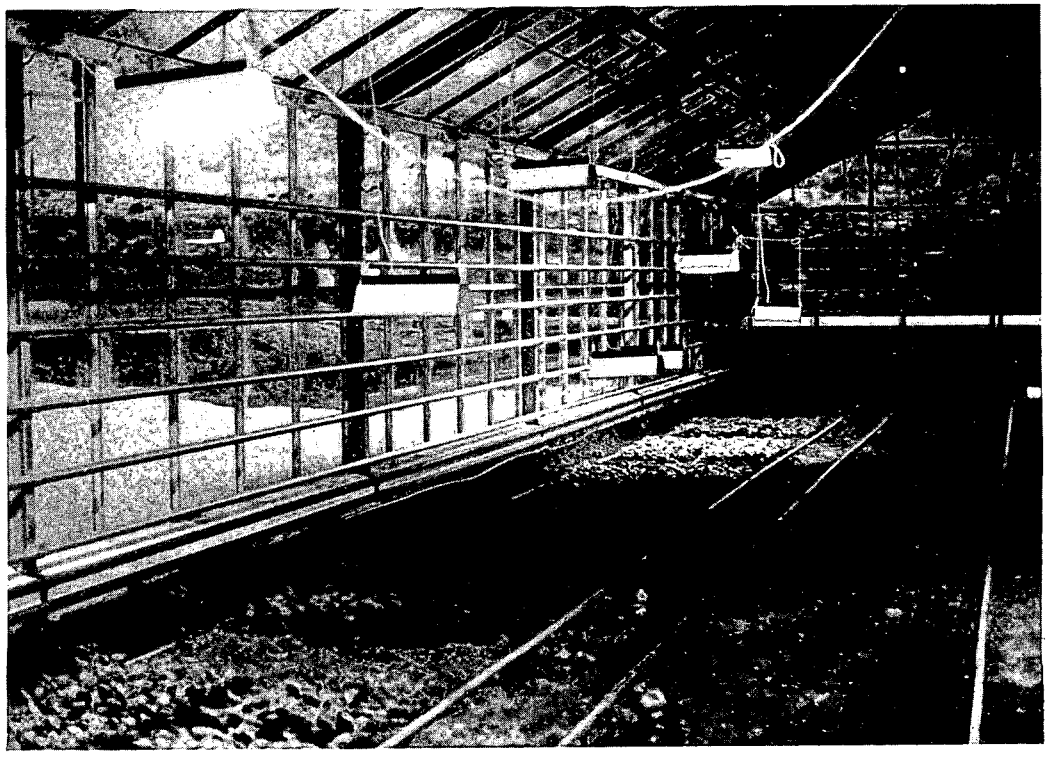

Figure III.B-2. Greenhouse in Iceland heated by geothermal energy. (CBB 785-5261)

thermal development in six countries (the United States, Canada, Iceland, Italy, New Zealand, and the Philippines) and found that the extent of government participation in direct applications projects varied widely. In France and Hungary, where government participation is strong, it is guided by a desire to encourage the development of geothermal resources. The general pattern is that the government will work in partnership with the private sector and guarantee the initial risks of demonstration in cooperation with the private sector. If the venture is successful, the private sector assumes responsibility for the project and repays investment costs (plus some agreed-to interest) to the government through sales of geothermal energy.

At the conclusion of the first phase of the study, the Working Subcommittee recommended that participating countries support efforts in five areas: geothermal exploration, demonstration of specific applications, research and development of new applications, education and information, and international cooperative projects. Specifically, the group agreed that the next phase of the project should address the topic of the economics of direct applications.

In addition to the report on the status of direct applications, the substudy has been instrumental in stimulating still other work in the United States on direct applications of geothermal resources.* Examples of CCMS-inspired efforts include:

*A summary of the U.S. Direct Applications programs is presented in Appendix 3-B.

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Phase II

The second phase of the Direct Applications Substudy began with an analysis of the value of geothermal energy for district heating and cooling, performed by the cooperative exchange of data between France, Iceland, and the United States. Iceland provided information on the design and operation of geothermal district heating systems. France provided information on the design of French geothermal district heating systems and on the computer simulation of these systems involving heat pumps, supplemental fossil heating capacity, and alternative heating delivery systems. The United States provided systematic analyses of the economics of geothermal district heating applications. These analyses used information obtained from France and Iceland to develop and verify a computer simulation model for geothermal district heating applications. The project was directed at the definition of key technical factors and key economic assumptions of geothermal energy for district heating and cooling. It endeavored to clarify appropriate financial analysis procedures and techniques.

The exchange of information was implemented through two visits by C. H. Bloomster of Battelle Pacific Northwest Laboratories to the Chatou Laboratories of Electricité de France in April and October 1976. These trips included stopovers in in Iceland, where information was obtained from the two consulting engineering firms that designed Iceland's district heating systems and the Reykjavik Municipal District Heating Service. Iceland also provided a complete description of the Sudurnes District Heating System, a new system designed to heat seven communities. The Icelandic system was simulated on the U.S. GEOCITY computer model and provided an opportunity for comparison of modeling efforts with an actual system.

Information on a German study on district heating was also obtained from O. Kappelmeyer, Federal Institute of Geophysics, Hanover, Germany. The information provided by France served to extend the data base and capabilities of the GEOCITY model to lower temperature systems. The French simulation model was concerned with district heating systems using heat pumps, supplemental fossil fuel boilers, and geothermal energy. The model was designed to optimize the energy output of individual systems subject to fossil fuel costs, geothermal energy costs, and tariff structures for electric power which vary sharply throughout the day and year. The French systems and analyses are specific to the French situation and are not directly applicable to near-term conditions expected in the United States and Iceland. However, the French experience may become more relevant to the U.S. effort if viable moderate temperature resources are identified and developed near major U.S. East Coast population centers.

Two technical meetings were held under this phase. The first meeting, C.D.S.M.: Étude Pilote Géothermie (CCMS Geothermal Pilot Study), held in Paris in June 1976, included the participation of Belgium, Canada, France, Greece, Iceland, Ireland, Italy, the Netherlands, Spain, Switzerland, the United Kingdom, the United States, and West Germany. Papers were presented on technical and economic aspects of geothermal space heating and on legal and institutional problems. The meeting concluded with a tour of new district heating systems at Creil (see Figures III.B-3 and III.B-4) and Villeneuve La Garenne.

In the course of the meeting, the economics of direct applications again emerged as the most interesting and compelling issue facing the geothermal community. It was agreed by the conferees that further work was needed on the subject, and a second technical meeting on the economics of geothermal direct applications was proposed.

A report was issued at the Paris meeting: La Géothermie: chauffage de logements (Geothermal Energy: Residential Space Heating) was subsequently translated into English by the United States (Reference 3).

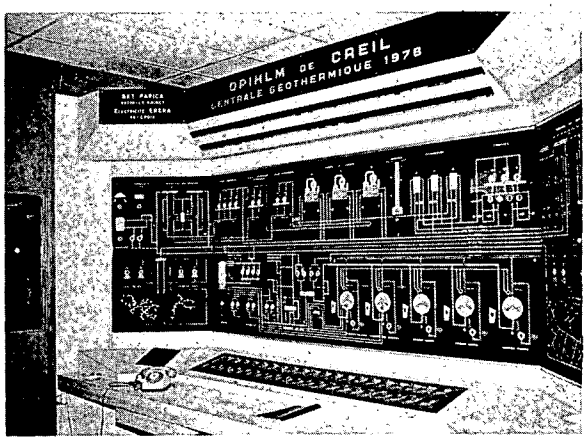

Figure III.B-3. Control instrumentation panel for district heating system at Creil, France. (XBB 785-5257)

Figure III.B-4. Apartment house heated by the district heating system at Creil, France. (CBB 785-5233)

The second conference of the substudy, on Economics of Direct Uses of Geothermal Energy, was held in Washington, D.C., June 21-22, 1977. Representatives of Canada, France, Great Britain, Greece, Iceland, Indonesia, Italy, New Zealand, Nicaragua, Turkey, the United States, and West Germany were present.

The three major participants in the space heating economics project each gave reports on the previous year's work. P. Sangnier (France) reported that projects at Creil, Villeneuve La Garenne and a military base were on line, and between eight to ten thousand housing units were being heated geothermally. In addition, ten to fifteen housing and agricultural projects are planned and Sangnier emphasized that investment risks and financing practices were a major factor in economics of space heating.

Exploration and drilling were continuing in Iceland, with the expectation that 65 percent of the population should enjoy geothermal space heating within a few years. Greenhouse farming was increased to 140,000 square meters by the end of 1976. Seaweed drying and salt production using geothermal heat were also under way.

The United States reported two significant accomplishments in its direct applications program. The first was the partial confirmation of the theory that granite plutons along the East Coast containing small amounts of naturally radioactive elements may be producing relatively warm underground water reservoirs at economic depths. A reexamination of oil drilling logs had shown the existence of one such warm water reservoir under Ocean City, Maryland. The existence of a low and moderate temperature resource in close proximity to a population center would greatly enhance the economic potential for direct application. The second accomplishment, presented by the Battelle group, was a set of calculations showing that under certain economic conditions, geothermal energy could be competitive with fossil fuels at distances up to fifty miles from the wellhead.

Representatives from Canada, New Zealand, Nicaragua, Indonesia, West Germany, and Turkey reported on the present status of geothermal development in their respective countries. Information concerning the status of direct applications of geothermal energy in some of these countries can be found in Appendix 2, "Status of Selected Geothermal Programs Throughout the World."

On the second day of the conference, simultaneous meetings were held on space/district heating and on industrial and agricultural applications. The French presented further details of the new town projects in the Paris Basin. Representatives of several ERDA laboratories and of the State of California gave presentations on their programs. Several architect/engineering and R&D firms involved in ERDA's first large-scale effort in direct applications presented preliminary results of engineering and economic studies. These included space heating systems for several small towns in California and Alaska, alfalfa drying and several different multiple-use concepts for agriculture and industry.

The conference on "The Economics of Direct Applications of Geothermal Energy" in June 1977 formally concluded the second phase of the direct applications substudy of the CCMS Geothermal Pilot Study. Proceedings of the conference will be published in July 1978 as CCMS Document No. 66. The present generation of direct applications programs in the participating countries can be properly evaluated in the Geothermal Pilot Study follow-up conference scheduled for 1980 in Paris.

U.S. IEA Proposal

To support continuing international interest in the area of direct applications, the United States has proposed that certain models of advanced heat exchanger equipment that have been successfully tested in the United States be considered for direct heat application testing by other countries in the International Energy Agency. The United States will either provide units directly or forward detailed design drawings for on-site fabrication by the host country. The estimated cost of fabrication is approximately $10,000.

CONCLUSION/FINDINGS

The major conclusions of the Direct Applications Substudy are as follows:

1. At present the rate of energy use associated with direct applications is a significant fraction of that produced as electric power. There is a wide variety of applications appropriate for moderate temperature geothermal resources in areas such as industrial processing, space heating, agricultural and aquacultural uses. Where currently used, such applications are almost always thermodynamically more efficient and often more economically attractive compared with conventional sources of energy.

2. In the area of direct applications, additional engineering experience is necessary to achieve optimum design of processes, equipment and the perfection of hardware. The practical evaluation of engineering concepts used in specific applications, e.g., improved and less costly heat exchangers, refrigeration of produce, production of synthetic fuels, protein farming, will support the future commercialization of direct use of geothermal resources.

3. There are institutional and economic constraints associated with direct applications of geothermal energy (such as the implementation of district heating systems) which require further analysis and definition. In addition, work is needed to improve the interface between electric and nonelectric applications.

RECOMMENDATIONS

The full potential for direct applications of geothermal energy has not yet been realized. Countries interested in direct applications should support domestic efforts in the following areas as part of an integrated effort of energy conservation and the expanded use of geothermal resources:

1. Geothermal Exploration. Programs to take inventory of national geothermal resources that are suitable for direct applications should be encouraged. Resource assessment programs should be carried out at a level of detail necessary for successful exploitation in direct applications.

2. Demonstration of Applications. Data from operating experience should be obtained to measure the economic feasibility of using geothermal heat directly compared with conventional energy sources. This information should be made available for public use.

3. Research and Development on New Applications. The evaluation of experimentally untested ideas for the application of geothermal resources should be supported beyond conceptual analyses through at least a phase of small-scale experience.

4. Financing. Government support for early financing favorable to the development of direct application will often be necessary. Such support might include guarantees of loans, attractive interest rates, and various forms of governmental financial participation in relatively high-risk applications and in applications that are apparently simple but are being undertaken for the first time.

5. Interfacing Electrical and Nonelectrical Applications of Geothermal Resources. Programs combining electrical and non-

electrical applications of the same geological resource should be encouraged.

6. Improvement of Legal Framework. Direct applications of geothermal energy are affected by existing laws. Although it is recognized that laws governing geothermal resource development vary from country to country, it is proposed that an appropriate review of the legal framework should be made in interested countries as a preliminary effort to identify the institutional barriers affecting the direct applications of geothermal resources.

It is recommended that the international exchange of information relative to direct geothermal applications be continued in order to maximize the effective use of internationally available technology and experience. In this context, the United States encourages the participation of the international community in the forthcoming review conference in 1980, at which time the IEA heat exchanger program may be reported.

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C. RESERVOIR ASSESSMENT SUBSTUDY

INTRODUCTION

While accelerated development of geothermal energy could provide a significant additional source of energy for the world, it is attended by several well-known but unresolved technical problems. There is a need for greater knowledge of reservoir mechanics, better methods for identification and assessment of geothermal fields, better and safer drilling techniques, better production techniques to prevent reservoir damage by scaling and corrosion, standardization of analytical procedures and better methods for minimizing environmental problems.

Research and development on the problems of fluid disposal, materials corrosion and scaling, and reservoir engineering were reviewed by a group of experts at the First International Geothermal Implementation Conference at Wairakei, New Zealand (Reference 1). Their objective was to identify problems of common interest which would be appropriate for international cooperative projects. Two technical areas--disposal of geothermal fluids and reservoir engineering--were identified for cooperative investigation in the Substudy on Reservoir Assessment.

Disposal of Geothermal Fluids

A major problem associated with the development of hydrothermal resources is the disposal of geothermal fluid after the heat is extracted. The amount of waste fluid normally ranges between 75 and 150 lb/kWh of electricity produced, depending upon the water temperature and the flashing pressure. Some geothermal fluids contain dissolved chemicals in concentrations which preclude surface disposal into waterways. Examples of chemicals and the acidity occurring in known geothermal fluids include:

Chemical Content	
NaCl	500-200,000 ppm
B	2-200 ppm
SO_4	1-1,000 ppm
As	<1-40 ppm
Acidity	
pH	7-1

Various methods have been used to dispose of geothermal brine around the world. They include surface discharge where the water is sufficiently pure (Iceland), evaporation and storage in ponds (Mexico), and injection (New Zealand, the United States, and Japan).

At the New Zealand Conference the group of experts on geothermal fluid utilization recommended that cooperative research should focus on injection technology for the following reasons:

1. to avoid the environmental problems resulting from the disposal of geothermal fluids into waterways;
2. to reduce subsidence; and
3. to contribute to the recharge of reservoirs, increasing the total fraction of energy that is extracted.

One problem with injection is that most geothermal hot waters contain

some dissolved solids, and the lowered pressures and temperatures at which such fluids are injected may cause precipitation of solids which in turn may plug fractures or pores in the reservoir. The net result could be a decrease in permeability and reduced capacity for accepting further injection fluids, to the inevitable detriment of productivity. Another problem associated with injection is the scaling that generally occurs in the injection equipment, surface channels, pipes, and wells. The activities of the CCMS Geothermal Fluid Injection Program will be presented in the body of this summary.

Reservoir Engineering

The purposes of reservoir engineering are to determine the quantities of geothermal fluid in a reservoir and to establish economical rates of utilization. These tasks cannot be satisfactorily accomplished with present techniques. Current geophysical studies can indicate the physical sizes of reservoirs in a general way, but they do not reliably establish the extent of recoverable geothermal energy in megawatt years. Successful integration of geothermal resources into the world energy mix awaits further refinement of many resource assessment techniques.

At New Zealand, the expert group on reservoir engineering noted that while some petroleum technology is applicable to geothermal resources, there is a specific need to undertake field studies in localities where considerable experience has been gained. These studies should include the following:

1. general field operations and field development,

2. local and regional geology,

3. hydrogeologic data,

4. well production histories,

5. pressure and temperature logs,

6. core and cutting analyses,

7. physical and chemical properties of reservoir fluids, and

8. well flow test data.

An overall objective of the CCMS Geothermal Pilot Study was to encourage the development of long-term international cooperative activities. In the area of reservoir engineering, this effort culminated in a bilateral agreement between the United States and Mexico in 1977 to undertake a cooperative investigation of the geothermal system at Cerro Prieto, which is in the same geological setting as the Imperial Valley. While the existence of a shared geothermal resource between the United States and Mexico would have encouraged a cooperative effort independently of other considerations, the CCMS Geothermal Pilot Study provided a supportive forum for discussions between representatives of the United States (Lawrence Berkeley Laboratory, the U.S. Geological Survey, and the Bureau of Reclamation) and Mexico (Comisión Federal de Electricidad) during the period 1975-1977, when both countries were in the process of accelerating their respective geothermal programs.

A discussion of cooperative reservoir assessment activities under the U.S.-Mexican Bilateral Agreement will be presented in Appendix 3-D.

CCMS GEOTHERMAL FLUID INJECTION PROGRAM

Objectives

The objectives of the Geothermal

Fluid Injection substudy are to identify those aspects of injection that are of common interest and to initiate appropriate programs to assist participating countries.

Design of Substudy

It was noted at the time of the First Geothermal Implementation Conference in 1974 that the Ministry of Works and Development in New Zealand and the Bureau of Reclamation in the United States were the only organizations planning experimental injection activities in the near future. Geothermal investigations conducted at the Broadlands geothermal field in New Zealand (Figure III.C-1) and the East Mesa geothermal field in the Imperial Valley (Figure III.C-2) provided an excellent opportunity to conduct cooperative injection studies. The two fields were sufficiently similar--both fields were of the liquid-dominated type and were associated with faulting systems--that both countries could benefit from the exchange of

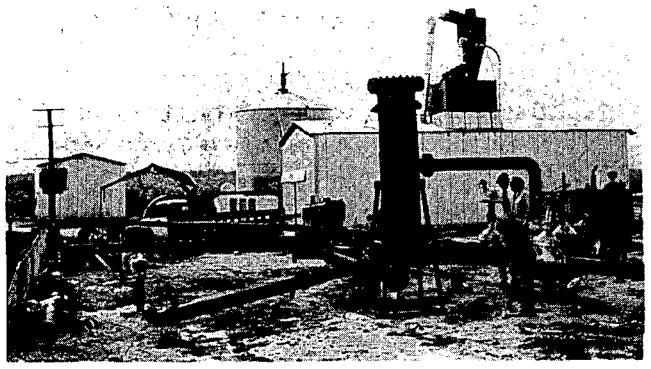

Figure III.C-1. An injection well used to dispose of waste fluid from an alfalfa pellet processing plant in the Broadlands geothermal area, New Zealand. The well is a spent geothermal production well (photo by the Bureau of Reclamation.)
(CBB 785-6187)

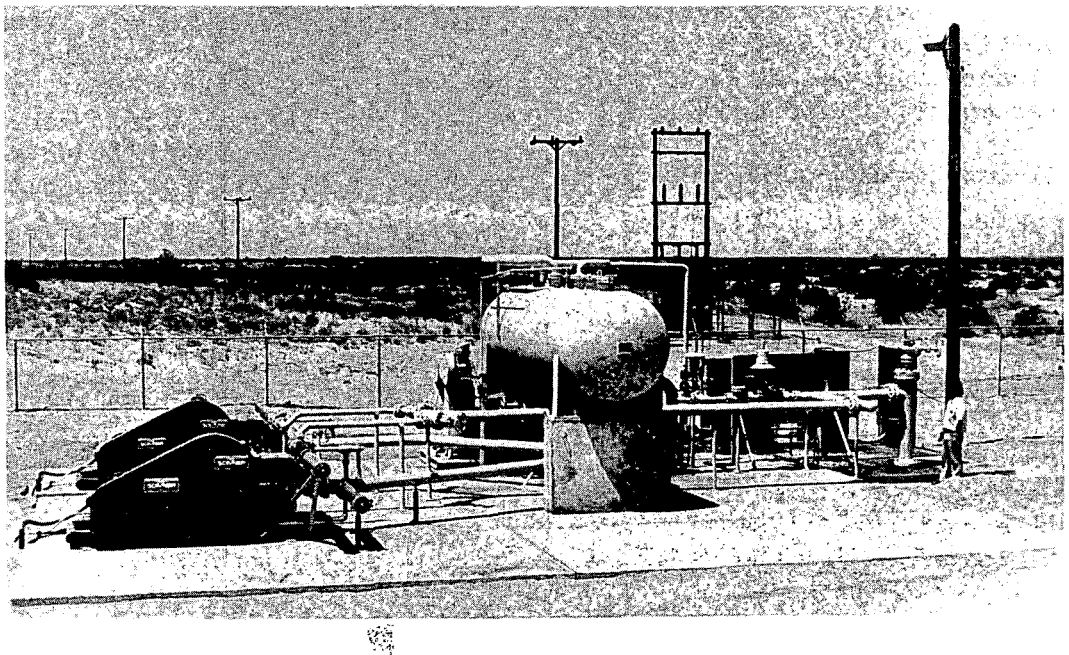

Figure III.C-2. An injection well and associated pumping apparatus at the East Mesa Test Site, Imperial Valley, California (photo by the Bureau of Reclamation).
(XBB 785-6297)

information. Development of a cooperative program was undertaken at a workshop of U.S. and New Zealand geothermal experts. Proposed areas for cooperation included:

1. design of proposed injection programs;

2. design of proposed monitoring programs, such as leveling and geodetic surveys, tilt leveling, tiltmeter surveys, extensometers, gravity, microseismic, resistivity, and borehole measurements such as pressure, temperature and flow;

3. progressive interchange of injection test data, results and interpretation;

4. studies in pretreatment of fluids;

5. investigation of corrosion and scaling problems in injection;

6. investigation of suitable radioactive, chemical dye, and other possible tracers; and

7. well completion methods.

Subsequently, two additional workshops were conducted which included the participation of geothermal experts from El Salvador, Mexico, France, and the Philippines as well as those from the United States and New Zealand. The workshops involved exchanges of data, meetings with operating and scientific personnel at on-line geothermal installations, and coordinated review and development of injection programs.

The Program

The first geothermal workshop on the injection of geothermal fluids was held at Wairakei, New Zealand, on November 18-27, 1974, with representatives from the U.S. Bureau of Reclamation and the New Zealand Ministry of Works and Development, the Department of Scientific and Industrial Research and the Committee on Energy R&D. At the workshop, participants drafted an informal agreement supporting an exchange of information between the two countries. This agreement was subsequently approved by the agencies involved and has provided a useful framework for exchanges of information.

Discussion at the first workshop began with a review of existing geothermal fields in New Zealand and the United States to ensure that all known aspects of the injection problem areas were considered. Items of mutual interest examined included (1) cooperative review of proposed injection programs followed by exchange of information and data during the injection operation, (2) methods and instruments used in the monitoring program, e.g., temperature and pressure surveys, level surveys, modeling of the reservoir, and the use of extensometers, tiltmeters, and flow measuring devices, and (3) subsidence monitoring methods in New Zealand and the United States.

The use of trace elements during injection operations has been attemped in both countries with little success. Discussion among participating experts suggested that radioactive elements such as tritium or iodine should be used to obtain measurable results.

As an extension to the First New Zealand Workshop, U.S. Bureau of Reclamation personnel visited Japan and met with Japanese geothermal engineers to discuss their operational injection experience.

The main reason the Japanese were injecting waste geothermal fluids was to prevent arsenic in geothermal

fluids from contaminating surface waters. Geothermal fluids in Japan contain from 2 to 10 ppm arsenic. The discharge of waste geothermal fluids into surface streams and the associated effect on fisheries downstream have become an environmental issue in Japan. The Japanese have injected geothermal fluids for several years and have obtained valuable data on injection activities.

Scale is a potential problem area in the development of any geothermal field. This is true for production as well as injection. In New Zealand and Japan, silica deposition appears to be the main cause of scale. Numerous methods of preventing silica from polymerizing and adhering to surfaces of piping and equipment are under study. Ponding tests were conducted to allow time for the silica to settle. It has also been found that silica may be removed by the addition of lime to the fluids. Alternatively, it was suggested that if geothermal fluids are injected at high temperatures, the silica will remain in solution.

The Second Geothermal Workshop on Injection of Geothermal Fluids was held in El Centro, California, on May 15-17, 1975, with representatives from the U.S. Bureau of Reclamation, New Zealand, El Salvador, France, and the Philippines.

At this meeting, the progress in geothermal fluid injection was reviewed. Investigators at the East Mesa geothermal field reported that one of the primary problems in injection was calcium carbonate scaling near the bottom of the injection well and in the geologic formations. Cleaning the well with both hydrochloric and hydrofluoric acids had improved the acceptance of geothermal fluids considerably. All fluid was being filtered before being injected, and facilities had been installed for chemical treatment of the fluid to help prevent the development of calcium carbonate scale.

The investigators also noted that mixing geothermal fluids from different wells increased the probability and rate of calcium carbonate scaling. The most recent injection activity at East Mesa included flowing of all waste fluids from geothermal operations into the brine holding pond and pumping from this pond to the injection well. Without ponding, care must be taken in proportioning the amount of fluid from each well to reduce the formation of calcium carbonate scale, although filtering with 25-micron bag-type filters had been effective.

The injection program in New Zealand was to involve the use of production wells at Broadlands that had ceased useful production. At the time of the second geothermal workshop (1975) injection had not yet been performed but was expected to be in the very near future.

Existing and proposed injection operations in France, the Philippines, and El Salvador were discussed and analyzed by participants at the meeting. Injection problems in these countries were similar to those in the United States and New Zealand. Scaling caused by silica and calcium carbonate seemed to be the primary problem in all injection activities. Tests are continuing in these countries to solve problems of scaling in their respective injection programs. Participants at the meeting agreed to furnish pertinent information on injection to other countries as it becomes available.

The geothermal fluid injection portion of the Reservoir Assessment Study concluded with the Third In-

jection Workshop, held in Taupo, New Zealand, on September 4-5, 1976. Injection activities in the following geothermal fields were discussed: Ahuachapan, Broadlands, East Mesa, the Paris Basin, the Geysers, and Larderello.

During the discussions a number of participants commented on special tests that could be made to evaluate the effectiveness of injection. Analyzing pressure build-up data could determine whether chemical deposition was occurring in the well bore or in the formation immediately around the well. Similar tests after acidizing the well could determine its effectiveness.

Sensitive pressure gauges are available which will provide useful information for pressure transient analysis and for interference testing between wells.

Tracer surveys have been undertaken at the Geysers geothermal field to determine the flow system of the field and the effect of injection on the system. Initial injection tests using tritium as a tracer showed no radioactivity in the steam after four months. Later, larger amounts of tritium were injected and detection was made within ten days. These tracer tests indicated that part of the injected fluid is being made available as steam in production wells. Tritium tracer has also been used in geothermal fields in El Salvador.

CONCLUSIONS

1. Geothermal Fluid Injection Workshops conducted under the aegis of the Geothermal Pilot Study have been valuable for sharing knowledge and expertise among the participating countries. However, considerable knowledge is still to be gained in the injection phase of geothermal programs.

2. Injection is a key element in satisfactory disposal of geothermal waste fluid. Scaling caused by silica and calcium carbonate seems to be the primary problem in all injection activities. Permanent methods for controlling scale formation in injection wells have not been perfected, but pH and temperature control appear promising.

RECOMMENDATIONS

Continued expert cooperation is needed to take effective advantage of work that has been accomplished in the identification, evaluation and resolution of injection problems.

There are several areas where continued cooperation among participating countries would be advantageous:

1. Interdisciplinary studies of problems associated with injection are needed. Up to now each discipline has made its own attack on disposal of waste fluids. Investigators should approach new injection problems with the objective of solving the common problem of field assessment and management. Future cooperation should address the following topics:

    a. Subsidence control--pressure maintenance, location of production and injection wells, evaluation of alternatives to injection.

    b. Reservoir evaluation--modeling and injection, effect of injection on recharge and on temperature degradation.

c. Mechanical and physical performance of subsurface formations--engineering, geology, and rock mechanics theory, and in situ and laboratory measurements.

d. Development of new corrosion-resistant materials--for handling geothermal fluids, e.g., special concretes, new metals and plastics.

2. Coordinated studies of injection should continue to draw upon computer modeling of ground water and geothermal reservoirs.

3. Direct exchange of data derived from evaluation of materials, equipment and instruments for use in geothermal injection test operations would facilitate development of appropriate hardware. This can also be accomplished through correspondence, on-site visits, or the transmittal of papers and articles to the Computer-Based Information Systems under U.S.-Italian sponsorship for periodic topical reviews of injection technology.

All interested countries are encouraged to participate in the 1980 follow-up international review conference for the Geothermal Pilot Study. By that time, there should be sufficient experience accumulated with injection activities for a useful discussion of the state of injection technology to take place.

REFERENCE

1. Summary Record of the First Geothermal Implementation Conference, New Zealand, 1974 (Department of Scientific and Industrial Research, New Zealand, 1974).

D. SMALL GEOTHERMAL POWER PLANTS SUBSTUDY

INTRODUCTION

Small power plants in the 0.5- to 5-MWe range are an important alternative to central power stations for developing geothermal resources. The large power stations of 50-100 MWe have two major disadvantages: they require large initial capital commitments and a large amount of lead time to determine if a resource is sufficient to support their development. This delays the immediate utilization of geothermal energy, and discourages the development of geothermal power in sparsely populated areas where the current power demand is quite low but where the availability of low-cost power would do much to enhance the economy of the areas.

The small power plant approach to geothermal development was considered at the CCMS Geothermal Pilot Study Planning Meeting in October 1973. The experts concluded that a cooperative investigation of small portable wellhead conversion systems is important for the following reasons:

1. A small geothermal power plant could provide electrical energy to remote locations where other generating methods were not satisfactory due to fuel costs or to transmission distance from a central generating facility.

2. A small geothermal power plant would allow production of electrical energy at the earliest possible time in the development of a geothermal field.

3. Finally, because technical problems associated with larger generating facilities would be present in the smaller systems, the smaller facilities would allow evaluation of these problems at lesser cost.

France, Iceland, Italy, Mexico, New Zealand, Portugal, Turkey, and the United States expressed an interest in this proposal and it was agreed that the United States, in consultation with interested countries, would determine more precisely how to advance international cooperation on small geothermal power plants.

OBJECTIVES

Construction of geothermal power plants involves numerous separate tasks which are most often accomplished by appropriate government agencies or private developers through consultation with a reputable architect/engineering firm.*

The objective of the Small Geothermal Power Plant Substudy is to increase the technical capability of participating countries, including those that have had no previous ex-

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*The consulting architect/engineering firm provides overall planning of the project and oversees scheduling and execution of numerous tasks associated with the construction of a geothermal power plant. It must be capable of (1) coordinating the resource exploration and evaluation activities and establishing optimum plant location; (2) establishing the size of the resource and its hydrothermal and chemical characteristics; (3) establishing power system characteristics to be interfaced with the new plant; (4) designing the site's civil improvements and plant module foundations; (5) designing the collection and reinjection system pipelines; (6) managing the procurement

perience with geothermal power utilization, for the design, procurement, and use of small power plants based on existing technology. The primary intention of the substudy is to apply the existing body of international experience in production of electricity from geothermal resources towards the design and installation of a small (5 MWe) geothermal power plant.

While the technology for small geothermal power plants is available, such systems use equipment that is largely non-standard; thus a secondary purpose of the substudy is to encourage the competitive development of key prototype equipment modules that have cost reduction potential because they are standardized and can be manufactured in quantity.

Design of Substudy

The Small Power Plant Substudy was organized in two phases. Phase 1 of the substudy was devoted to the development of a conceptual design for a 2- to 5-MWe geothermal power plant. A system concept for a 5-MWe power plant was reviewed at two international conferences in 1975, at Berkeley, California, and the Azores, Portugal. During Phase 2, a set of guidelines for procurement and construction of a small geothermal power plant was prepared by Rogers Engineering Co., Inc. (USA) in cooperation with a committee from Italy, Japan, New Zealand, Turkey, and the United States.

THE PROGRAM

Because of the diverse interests and needs that a small geothermal power plant would be likely to serve, the United States commissioned a conceptual design report to examine the costs, construction and assembly time for a small-scale geothermal power plant and its potential utility as a training facility (Reference 1). This study was first presented to the representatives of fifteen countries at the First Conference on Small-Scale Geothermal Power Plants during Phase 1 of the study, along with a proposal for a three-phase cooperative program under CCMS auspices. The proposed program would begin with a survey of needs and design concepts leading towards a demonstration project at a particular site and an evaluation of the results.

The design study involved a system concept for a standardized steam turbine-driven electric generating plant of 2- to 5-MWe capacity, operating on steam derived from a liquid-dominated hydrothermal reservoir of approximately 205°C reservoir temperature. The power plant consisted of four factory-assembled modules, selected to minimize the amount of assembly and installation work required in the field and to be readily transportable by truck and lowbed trailer. The modules consisted of a steam separator, a turbine generator unit, a condenser,** a switch gear module and a prefabricated building with lavatory, office, supply storage,

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and detailed design of all modules; (7) designing and procuring the module interconnections; (8) specifying and procuring appropriate alternative or optional units; (9) managing the construction, startup and training activities associated with fully implementing a geothermal power plant.

**The condenser would be a barometric condenser with a once-through cooling system where an adjacent source of cooling water is available. If water is not available, the condenser would be eliminated and the turbine would be a back-pressure turbine.

and equipment maintenance areas. When operating under design conditions, the generator produces 5,000 kW in the condensing mode. When it is operating in a backpressured mode exhausting to the atmosphere, maximum output is approximately 2,200 kW.

Costs of the proposed 2- to 5-MWe power plant were estimated to be $1.8 million (First Quarter 1975) installed at a typical location (approximately fifty miles from a port) with condensing equipment, and $1.5 million for the noncondensing version. For the condensing unit, this would amount to $375 per kilowatt installed, exclusive of drilling costs. Alternatively, cost for a 2.2-MWe backpressure plant would amount to $685 per kilowatt installed. This compared favorably with capital costs of 50-MWe geothermal central power stations, which average $500-$700 per kilowatt installed.

In the discussion of the proposal, it was clear that the needs, resources and interests of the participants varied greatly. The definition of "small" ranged from 100 kWe to 5 MWe; the definition of "low and moderate" resource conditions ranged from 100°-200°C, in some cases even including a dry steam resource for a "small" power plant. Representatives from France, Mexico and Portugal expressed considerable interest in the establishment of a small power plant project. Ing. Jorge Guiza of Mexico offered a site in the Cerro Prieto geothermal field for testing small power plants, and Dr. Alain Gringarten of France suggested that small modular plants be produced for rental to users in the early stages of resource development.

Discussion of the small power plant concept continued at the Second Conference in the Azores in September 1975. The tasks of the second meeting were (1) to discuss what should be done to develop small power plants in countries participating in the substudy, and (2) to evaluate the potential of the Azores as a case study for a small power plant development program.

Representatives from Portugal, France, Nicaragua, Yugoslavia, Japan, and the United States described their activities in geothermal development, particularly the potential application of small power plants.

Geothermal development in the Azores started with the drilling of an experimental hole that encountered fluid temperatures of 200°C at roughly 900-m depth. A system of small power plants is planned (the first one will be 3 MWe) to phase out dependence on hydropower so that the water can be used for irrigation and power plant cooling. Installed generating capacity was 14.9 MWe in 1975 on Sao Miguel, with a population of 180,000 people. The potential for direct heat applications of geothermal energy in the Azores includes food processing (sugar, powdered milk, agar-agar), greenhousing, canning, space heating, and production of fresh water. Portugal has announced plans to establish an experimental geothermal laboratory in connection with a proposed Earth Sciences Institute in the Azores to oversee the development of geothermal energy.

France discussed its experience overseas in French Somaliland, the French West Indies, and Guadeloupe. Construction of small power plants in the 2- to 4-MWe range was being planned for Djibouti and Martinique. In Guadeloupe, the major electrical demand is about 70 MWe for nickel processing; and private industry and government are cooperating to produce steam and electricity.

Geothermal development was initiated in Nicaragua in 1972 with assistance from the United Nations after an initial survey found 209°C water at 220 m. The project was delayed and partially destroyed as a result of the 1972 earthquake; work resumed again in 1973. Exploratory drilling has begun at Momotombo and San Jacinto. Initial tests suggest that the system can produce on the order of 100 MWe per field.

Yugoslavia is planning to produce power from hot water discovered during oil drilling attempts. Their problem is how to handle the carbonates in the fluids which form calcite deposits in the well-bore and surface piping.

An industry representative from Japan described the four power plants then in operation at Otake (13 MWe), Onuma (10 MWe), Matsukawa (20 MWe), and Onikobe (20 MWe). Existing power plants at Otake and Onuma are both single-cylinder impulse turbines. A 1-MWe binary fluid cycle demonstration pilot power plant was installed in 1977 at the Otake Power Plant site.

Representatives from the United States discussed ongoing U.S. programs in geothermal development. James Bresee described a joint government and industry effort to add a 10-MWe power plant to the Geothermal Loop Experimental Facility at Niland, California. Anders Lundberg presented the results of investigations at Lawrence Livermore Laboratory concerning potential use of small power plants in Alaska. Assuming that the cost of oil per barrel is $100 at some remote Alaskan locations, an allowable investment in small geothermal power plants to replace present diesel plants could be as high as $4,000 per installed kilowatt. These economics might be improved slightly if the waste heat from the power plants is used for nonelectric purposes.

Delegates to the Azores workshop visited electric power plant sites on Sao Miguel, Faial, and Pico. Electricity to the consumer in the Azores varied from 6.16 cents per kWh (Sao Miguel) to 15.4 cents per kWh (Pico).

At the conclusion of the Azores workshop the delegates endorsed the concept of a small geothermal power plant and determined that a set of design guidelines, based on the initial system concept, should be prepared to support development of a prototype small power plant. The guidelines would be available to all interested countries and international organizations for adaptation to a particular location. The document would also serve as the basis for a detailed design of a prototype power plant. Fabrication of a small power plant was regarded as beyond the scope of the Geothermal Pilot Study because it would involve between one to two million dollars and would require supporting technical and financial commitments beyond the pilot period.

Under Phase II of the substudy, Rogers Engineering Company, Inc., an architect/engineering firm with experience in geothermal power, was commissioned by the United States to prepare a draft set of design considerations and technical guidelines based on their earlier conceptual design for a modular small power plant. The draft guidelines were reviewed by a committee of international experts from Italy (P. Ceron), Japan (K. Aikawa), New Zealand (R. S. Bolton), Turkey (O. Mertoglu) and the United States (J. C. Bresee). The final report, "Modular 5-MW Geothermal Power Plant Design Consideration and Guidelines" (hereafter Design Guidelines), was published in May 1976 (Reference 2).

The guidelines are intended to inform the potential owner and equipment manufacturer of the features and requirements essential to the reliable design and installation of a small geothermal power plant. By making available the collective international experience with small power plants in the form of technical parameters and design considerations, it also supports the tasks of the architect/engineer in charge of design, procurement and construction of a specific small power plant. It is expected that this effort will accelerate development of known geothermal resources and will help developing countries become self-sufficient in energy.

The design guidelines define the requirements for basic power plant modules and optional units, and describe a basic framework for contracts involving plant site preparation, foundation and utilities construction, installation and assembly activities and miscellaneous material supplies. The six basic modules are a turbine generator, a condenser and noncondensable gas removal system, a plant control and switchgear module, a cooling water circulation pump, a steam-water separator, and a maintenance, office and lavatory module (see Figure III.D-1). The alternative or optional units include an injection pump, cooling tower, spray pond installation and pumping units, and an auxiliary generator.

No specific cost estimates are provided with the Design Guidelines. However, an estimate of current 1978 costs based upon a 28 percent increase over the original 1975 estimate of $1.8 million would amount to $2.3 million for the condensing version and $1.9 million for the noncondensing version. Cost estimates may be derived from individual manufacturer's quotations for each needed module or a package quotation for the entire power plant. It is thought that for power plant units of 3-5 MWe, package quotes may be more appropriate, since individual quotes will require additional estimates for interface engineering of the modules involved.

In the example shown in Figure III.D-1, steam to the power plant is supplied from a single-stage flash steam separator unit which is supplied from two wells at a nominal pressure of 3.8 Kg/cm^2 Abs (54 psia). At the option of the owner, the unit may operate either with or without a condenser (nominal 5 MW and 3 MW respectively). In addition, the plant may be operated at turbine inlet pressures ranging from 3 to 10 kg/cm^2 Abs (43 to 142 psia), depending on the resource pressure available. The plant output capability is determined by the steam supply pressure and rate of flow.

Generally, there is a built-in margin of tolerance for small power plants that permits them to operate without penalty 10 percent above or below the design reference point, taking into account the gradual thermal degradation of the geothermal resource over time. However, if greater variations in resource conditions are experienced, new design parameters should be set to maximize production efficiency. On a specific project, the architect/engineer in charge will establish actual values for the individual modules.

Since no specific geothermal reservoir conditions could be identified for the preparation of the guidelines, hypothetical parameters (turbine inlet steam conditions, site environmental conditions and topography, geothermal resource brine, noncondensable gas content and analysis, selected power generation frequency, etc.) were established to permit the sizing of the

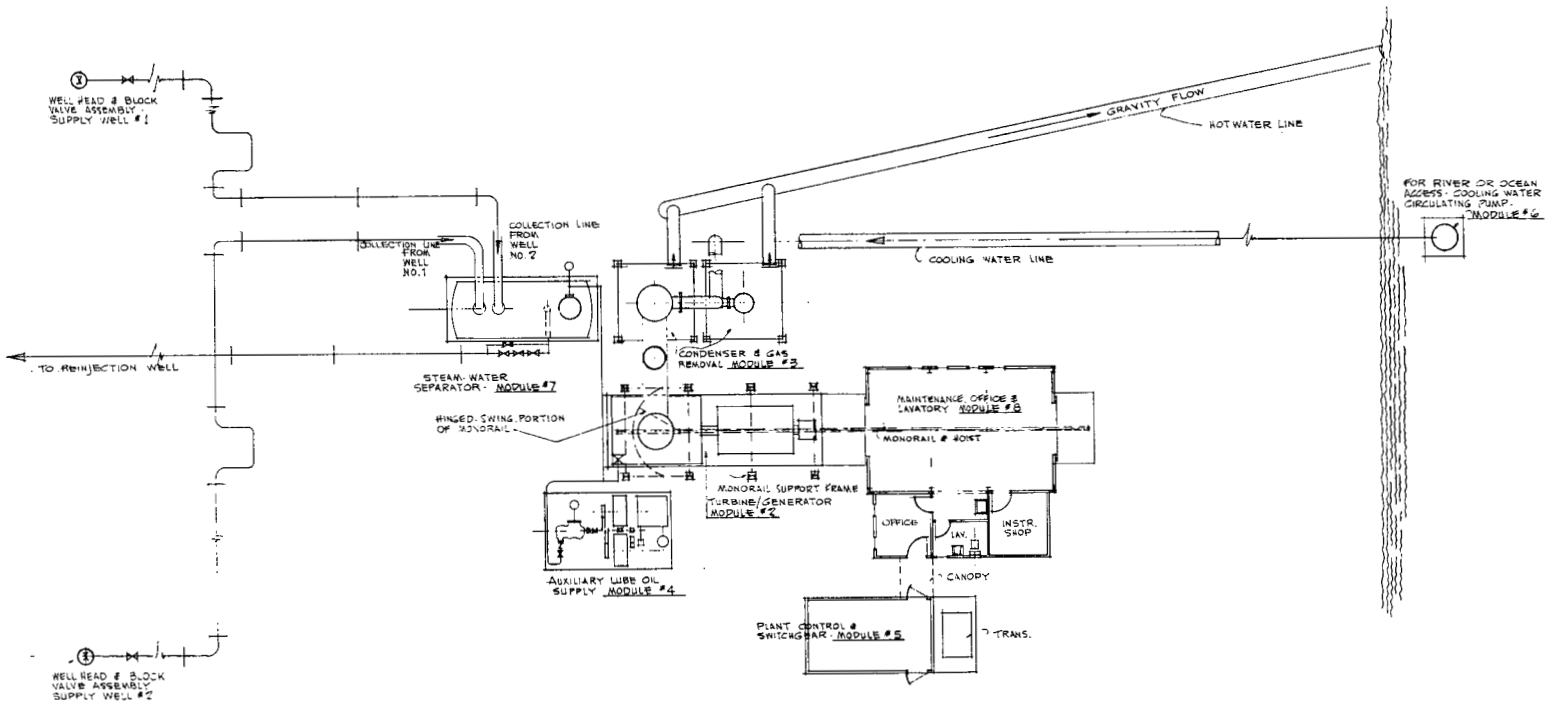


Figure III.D-1. Schematic plant layout of a 5-MW geothermal power plant (by Rogers Engineering Co., Inc.). (XBL 785-8733)

equipment. The values used in the Design Guidelines indicate equipment sizes that are realistic for the assumed conditions. However, it should be noted that in some locations, the content of noxious noncondensable gases in the resource fluid, such as hydrogen sulfide (H_2S), may be higher than the allowable discharge limit. In such cases, a shell and tube condenser should be substituted for the direct contact type condenser specified in Section 3 of the Guidelines and an additional module containing an H_2S removal system added.

Since the inception of the Small Power Plant Substudy in 1974, the concept of small-scale geothermal power plants (or wellhead generator units, as they have come to be called) has gained acceptance as an appropriate technological approach to geothermal development in many areas of the world. Small power plants are used to provide electricity to isolated areas, as in Turkey (see Figure III.D-2) as well as for the incremental development of large geothermal fields, as in El Salvador and the Philippines. Table III.D-1 presents typical examples of small power plants presently existing, under construction and planned in the participating countries of the pilot study. At least partial credit for this increased application can be assigned to the CCMS Substudy on Small Power Plants. Further demonstrations of the utility of small power plants will be forthcoming as individual countries proceed with their geothermal development programs.

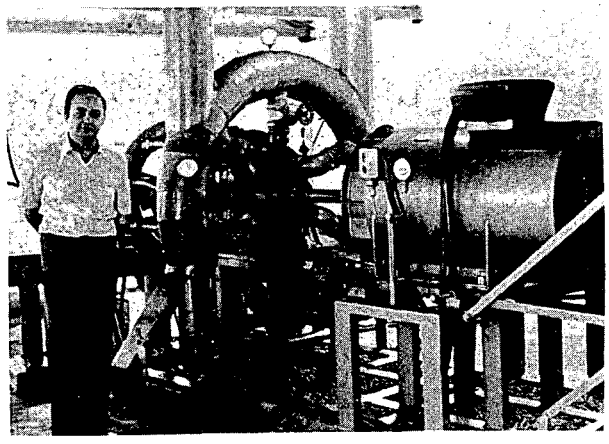


Figure III.D-2 Orhan Mertoglu stands beside the turbine he designed for the 0.5 MWe pilot geothermal power plant at Kizildere, Turkey. (CBB 785-6272)

United States Proposal to IEA

In support of continuing international interest in small geothermal power plants, the United States has offered to make available to member countries of the International Energy Agency, for on-site testing and evaluation, a 1.2-MW helical screw expander unit, now being tested in southwest Utah in the United States. The helical screw expander unit is designed to permit the use of small wellhead generators where the type of brines presently discourage the use of conventional systems such as those reviewed by the Design Guidelines. The assembly of the helical screw expander consists of five items, one major unit and four auxiliary systems as described below:

Expander Assembly
- 23' x 6' x 8'2"
- 1,127 ft^3
- 24,000 lb

Oil Console
- 11'6" x 4'10" x 7'2"
- 398 ft^3
- 3,000 lb

Load Bank
- 12' x 6'6" x 7'9"
- 603 ft^3
- 2,000 lb

Table III.D-1. Small power plants presently existing, under construction, or planned in participating countries.

Countries	Geothermal Field	Type of Power Plant	Capacity	Output	On Line
Japan	Kyushu, Otake	Flash, Condensing	13.0MW	10.0MW	1967
	Onuma	Flash, Condensing	12.5MW	10.0MW	1973
	Kyushu, Otake	Binary	1.0MW	1.0MW	1977
Philippines	Leyte	Flash, Non-condensing	3.0MW	3.0MW	1977
	Los Baños	Flash, Non-condensing	1.3MW	1.2MW	1977
Portugal	Sao Miguel	Flash, Condensing	5.0MW		1979
Turkey	Kizildere	Flash, Non-condensing	0.5MW	0.5MW	1976
El Salvador	Ahuachapan	Flash, Non-condensing	1.3MW	1.1MW	1975
United States	Roosevelt	Helical Screw	1.2MW	1.2MW	1978
	Raft River	Binary	5.0MW		1979
	Puna, Hawaii	Flash, Condensing	3.0MW		1979

Cable
1 78" reel
2,720 lb

Cable Trays
52 ft^3
200 lb

Optional additional equipment includes a remote control console and an instrumentation console which would add an additional 40 ft^3 and 100 lb. Estimated transportation costs from the West Coast of the United States to Europe are approximately $12,000.

CONCLUSION/FINDINGS

1. CCMS Report No. 49, "Modular 5-MW Geothermal Power Plant Design Considerations and Guidelines," is a useful background document that describes the technical requirements for the design and installation of a general purpose small power plant based on conventional technology. Preparation of the Guidelines has been a relatively inexpensive method of bringing together the broad concepts and international experience involved and sharing it with countries that did not have any prior experience in geothermal power production.

2. Since the inception of the CCMS study in 1974, small geothermal power plants have gained acceptance as an appropriate technology approach to production of electric power from geothermal energy in many isolated areas of the world. Small power plants have also facilitated the early economic production of large geothermal fields by providing

an opportunity for developers to obtain an early return on their investment as well as important reservoir data.

3. While presently available conversion technology can deal with geothermal brines of average salinity and chemical content, the economical application of the small power plant approach to more difficult brines will require the development of advanced engineering concepts.

RECOMMENDATIONS

1. Both national power authorities and equipment manufacturers are encouraged to review the guidelines for assistance in the design, procurement, construction, and production of specific power plants.

2. Future geothermal development should consider the use of wellhead devices as a direct power source for industrial users in integrated systems that combine electric power production with direct applications.

3. With general acceptance of conventional small power plants, future international cooperation in this area should be directed at advanced engineering concepts. Such an effort can increase the versatility of small power plants with respect to available geothermal resources as well as improve the overall economics of small-scale geothermal power production.

REFERENCES

1. Rogers Engineering Co., Inc., "Conceptual Design of 5-MW Wellhead Located Geothermal Steam Turbine Driven Electric Generating Plant," Lawrence Livermore Laboratory, Livermore, Report UCRL-13635 (April 1975).

2. Rogers Engineering Company, Inc., "Modular 5-MW Geothermal Power Plant Design Considerations and Guidelines," Lawrence Livermore Laboratory, Livermore, Report UCRL-13684 (May 1976). Also NATO-CCMS Report No. 49.

E. HOT DRY ROCK CONCEPTS SUBSTUDY

INTRODUCTION

The term Hot Dry Rock (HDR) refers to a geological formation below the earth's surface that has an abnormally high heat content but does not contain sufficient water or is not sufficiently permeable to allow withdrawal of the heat in commercially useful quantities. There are two major kinds of HDR heat sources: igneous-related HDR which results from heat transferred to surrounding rock from bodies of magma and HDR in the earth's crust which is heat transferred principally by regional conduction from the earth's interior.

One of the major problems impeding the utilization of the world's hot dry rock resources is the state of resource exploration and assessment. That is, how does one find the resource and determine the amount of economically recoverable heat from it? Resource exploration and assessment techniques for HDR are not as advanced as those used to find and assess hydrothermal resources. Experts believe that the world contains large amounts of heat below the surface; the U.S. alone is estimated to have over ten million quads (10^{22} Btu) at temperatures greater than 150°C at potentially economic depths. Countries such as Switzerland, Egypt, Turkey, Sweden, West Germany, and the United Kingdom are investigating the possibility of economic development of HDR resources.

Another major problem facing HDR development is the technology of resource extraction. A key research and development question facing engineers and geologists working in HDR today is whether they can develop equipment and techniques to extract the heat economically and in an environmentally acceptable manner. The high temperature and hard rocks encountered in geothermal exploration and development produce a new working environment that cannot be dealt with adequately by conventional petroleum technology. Technical areas of concern are drilling, fracturing, stimulation, mapping, and modeling of HDR systems.

OBJECTIVES

Several objectives for the Hot Dry Rock Concepts Substudy directly influenced the program content. The first objective was to stimulate international interest in Hot Dry Rock by providing geothermal experts in CCMS member countries with a broader scientific understanding of the concepts. A second objective was to stimulate cooperative efforts. Such activity would make effective use of the limited pool of experts and help cultivate an environment conducive to critical discussions of existing HDR technology and to the creation of new approaches and techniques. The third objective, closely related to the first two, was to disseminate as much information as possible on the U.S. HDR program for use in foreign programs to minimize unnecessary duplication of effort, and to encourage the development of complementary programs.

THE PROGRAM

To meet the above objectives, a two-part program was initiated for the Hot Dry Rock Concepts Substudy. The first part of the program focused on exchange of information and the second on visits by qualified scientists to Los Alamos Scientific

Laboratory (LASL), the present home of the U.S. HDR program.

Exchange of Information

Information was disseminated through technical reports on the LASL Hot Dry Rock Project and two international conferences.

The first meeting, "Information Meeting on Dry Hot Rock Geothermal Energy," was held at LASL on September 17-19, 1974. It was attended by experts from Canada, the Federal Republic of Germany, France, Italy, New Zealand, Nicaragua, Sweden, and Turkey, and from U.S. federal and state government departments and agencies, national and independent laboratories, universities, and industrial organizations. Reports were presented on NATO-CCMS activities in general, the NATO-CCMS Geothermal Pilot Study and its programmatic components, geothermal activities in the various countries represented at the meeting, the geothermal programs of the U.S. AEC and the National Science Foundation, and the LASL and Marysville programs. The proceedings of the meeting were published in December 1974 (Reference 1).

The "Second NATO-CCMS Information Meeting on Dry Hot Rock Geothermal Energy" was held at LASL on June 28-30, 1977. The meeting focused on recent developments in the U.S. Hot Dry Rock Program. Representatives of the U.S. Geological Survey and the Energy Research and Development Administration reported on the results of the Hot Dry Rock Assessment Panel Study. Investigators from LASL described alternative methods for heat extraction and updated participants on the progress of LASL geothermal energy and geosciences programs since the time of the first information meeting. The proceedings of this second information meeting were published in November 1977 (Reference 2).

Visits

The second component of the CCMS Hot Dry Rock Substudy consisted of visits to the LASL project (see Figures III.E-1 and III.E-2) by scientists and engineers from outside the United States. Extended visits were made to LASL by fourteen individuals from six countries:

Federal Republic of Germany:
Georg Delisle, Peter L. Ernst, Klaus John, Reinhard Jung, Harro Lorenzen, Gerhard Suhr, Jurgen Wohlenberg, and Rainer Wunder

Finland: Liisa Kivekas

France: Jean Paul Sarda

Italy: Antonia Palama and Paolo Del Gaudio

Japan: Eizo Yamada

United Kingdom: Anthony S. Batchelor

Except for the visitors from Finland and Japan, each of whom spent only about two weeks at LASL, all of the above spent two months or more working as staff members in one of the LASL geothermal energy groups, became directly involved in its programs and problems, and contributed to its progress. All have reported in detail in their own countries on the LASL project, and nearly all have continued to exchange information with LASL staff members in the areas of their own special interests and expertise, thereby fulfilling the objectives of the substudy. Two reports written by visiting scientists are:

G. Delisle, "Determination of Permeability of Granitic Rocks in GT-2 from Hydraulic Fracturing Data," Los Alamos Scientific

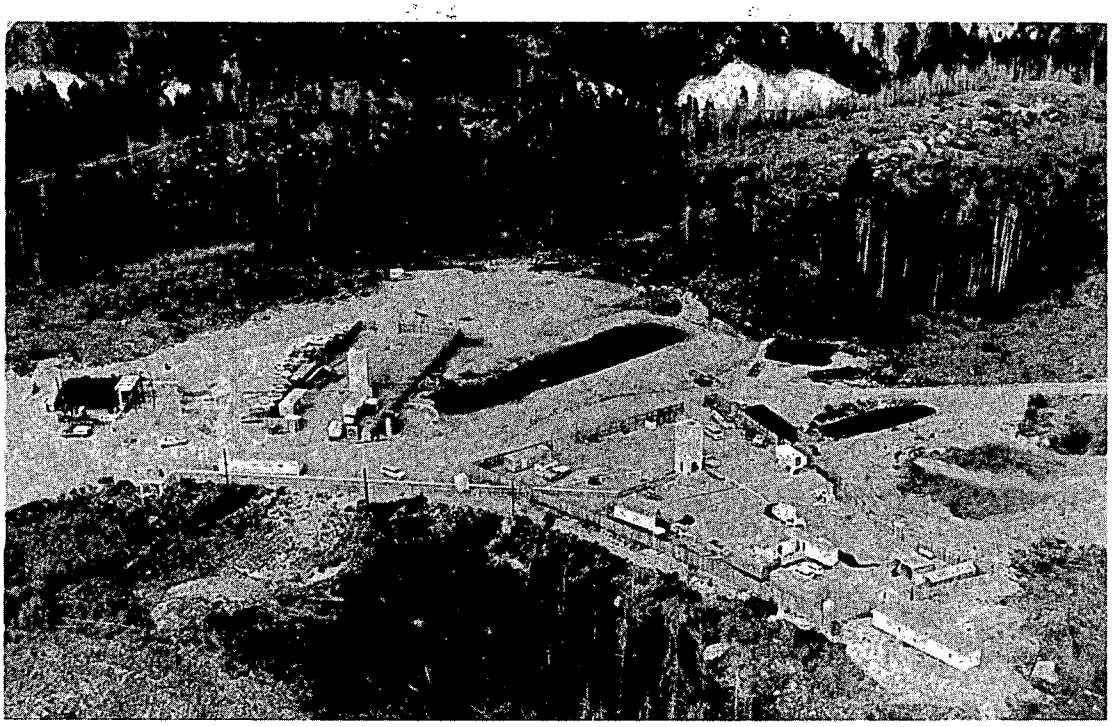


Figure III.E-1. The Fenton Hill hot dry rock extraction loop in New Mexico. (XBB 785-6275)

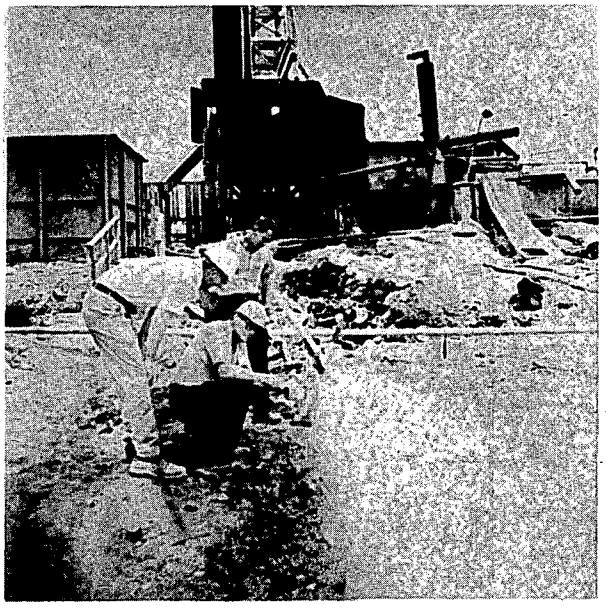


Figure III.E-2. Steam produced at the Fenton Hill experimental site. (XBB 785-6276)

Laboratory, Albuquerque, New Mexico, Report LA-6169-MS (December 1975).

J. P. Sarda, and Y. C. Hsu, "Angle of Crack Propagation for a Vertical Hydraulic Fracture," Los Alamos Scientific Laboratory, Albuquerque, New Mexico, Report LA-6175-MS (December 1975).

For the shorter visits, scientists came from the following countries under the CCMS program:

Australia
Austria
Canada
Denmark
Federal Republic of Germany
France
Iceland
Indonesia
Italy
Japan
Mexico
New Zealand
Nicaragua
Norway
Sweden
Switzerland
Turkey
United Kingdom

Growth of Interest In HDR

In 1973, besides the work at LASL, the only other effort in HDR was some mathematical modeling done in the Federal Republic of Germany. Today, interest has grown considerably, as shown by the following activities listed below in Table III.E-1, reported in the proceedings of the "Second NATO-CCMS Information Meeting on Dry Hot Rock Geothermal Energy."

Accomplishments

The Hot Dry Rock Concepts Substudy has contributed to the development and understanding of this potential source of energy in several ways. It has contributed to the body of knowledge in the geosciences for identifying, evaluating, developing and exploiting hot dry rock geothermal reservoirs. Worldwide investigations have been initiated in specific locations that appear promising for resource exploitation when the technology for doing so has matured. Finally, encouraging progress has been made in the development of equipment and methods needed to extract the heat from the hot dry rock in the earth's crust.

As a result of the substudy's efforts to make energy planners more aware of the potential of Hot Dry Rock resources, HDR and related programs have been established in the Federal Republic of Germany, France, Egypt, Italy, Sweden, Turkey, and the United Kingdom. This CCMS program has also helped to lay the groundwork for a study on "Man-Made Geothermal Energy Systems" under the International Energy Agency. The Federal Republic of Germany, Sweden, Switzerland, the United Kingdom, and the United States are all signatories to this fifteen-month, $600,000 study which started in 1977.

CONCLUSION

The Substudy on Hot Dry Rock Concepts has stimulated international awareness of the potential of hot dry rock resources, in part through exposure to the program at Los

Table III.E-1. Hot dry rock studies undertaken by various countries.

	Field Studies	Laboratory Studies of Permeability Enhancement	Modeling Studies of Fluid Flow and Heat Transfer	Field Experiments	Economic and Feasibility Studies
Egypt	x				
Federal Republic of Germany	x	x	x	x	
France		x	x		
Iceland					x
Italy	x			x	
Sweden	x				
Switzerland	x				
Turkey	x				
United Kingdom	x			x	
United States	x	x	x	x	x

Alamos Scientific Laboratory. This awareness has encouraged further cooperative efforts among several nations to determine the nature and extent of their resources suitable for hot dry rock systems.

RECOMMENDATIONS

1. The dialogue initiated among the many countries who have participated in or observed the Hot Dry Rock Substudy, as well as the informal visits to each other's facilities, should continue to support further refinement of this promising source of energy. Various mechanisms are available, such as international conferences, national conferences open to foreign attendees, international workshops on specific topics, and laboratory-to-laboratory visits.

2. Experiments should be initiated at more than one site to test the applicability of equipment and methods of various geologic formations composed of hot dry rocks. For example, downhole tests similar to those occurring at Fenton Hill, New Mexico, could be tried in the Urach area of West Germany, where drilling activities have been initiated.

3. The possibility of closer ties between those drilling deep exploratory wells for hydrothermal systems and those developing hot dry rock technology should be investigated. This multiple use approach could save time and effort and lead to a better understanding of the geology of the area.

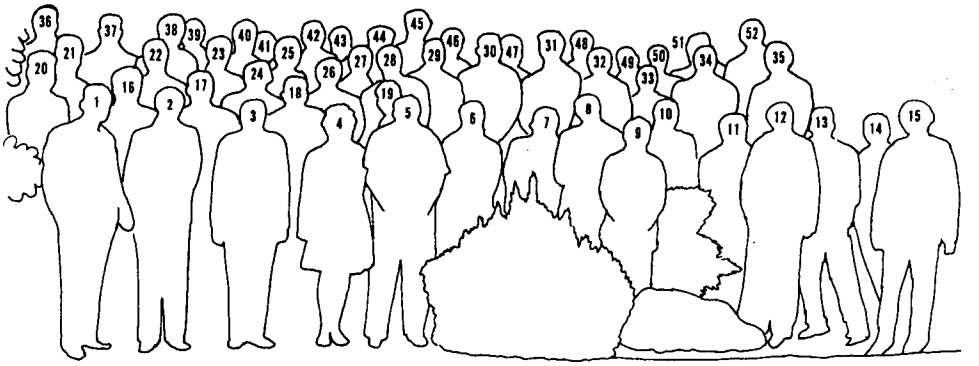
REFERENCES

1. J. W. Tester, Proceedings of the NATO-CCMS Information Meeting on Dry Hot Rock Geothermal Energy, (Los Alamos Scientific Laboratory, Albuquerque, December 1974), CCMS Report No. 38.

2. J. J. Mortensen, Proceedings of the Second NATO-CCMS Information Meeting on Dry Hot Rock Geothermal Energy, (Los Alamos Scientific Laboratory, November 1977), Report LA-7021-C. Also NATO-CCMS Report No. 65.

APPENDIX 1. PARTICIPATION IN MAJOR CONFERENCES OF THE CCMS GEOTHERMAL PILOT STUDY

Participants at the Expert Planning Meeting, October 1-5, 1973.
(XBB 785-6278)



1. K. Ragnars, 2. L. Valete, 3. S. Alpan, 4. N. K. del Grande, 5. J. Combs, 6. P. Muffler, 7. B. Ogle, 8. G. Kolstand, 9. K. Baba, 10. D. Stewart, 11. G. Facca, 12. P. Sangnier, 13. M. Smith, 14. A. Maimoni, 15. O. Kappelmeyer, 16. B. Fournier, 17. B. Leonard, 18. F. Fulton, 19. J. P. Munier-Jolain, 20. M. Reed, 21. J. Bresee, 22. S. Larson, 23. S. Gitterman, 24. R. Austin, 25. D. Quinsey, 26. J. Kahn, 27. A. Mendes, 28. J. LaVigne, 29. P. Ceron, 30. B. Ramsey, 31. J. Ellis, 32. S. Mercado, 33. S. Paredes, 34. A. Simonpietri, 35. J. Howard, 36. A. Blackwell, 37. K. Mirk, 38. B. Stilwell, 39. D. Lyon, 40. J. Souther, 41. J. Guiza, 42. P. Witherspoon, 43. J. Kunze, 44. K. Fulcher, 45. L. Werner, 46. R. Kingston, 47. K. Seal, 48. A. Jessop, 49. E. Tongiorgi, 50. J. Bloom, 51. F. Hodsoll, 52. A. Lundberg.
(XBL 785-8749)

PARTICIPATION IN PILOT STUDY PLANNING MEETINGS

Nationalities of Participants	Experts Meeting Oct. 73	Implementation Meeting N.Z. 1974
Canada	4	1
Federal Republic of Germany	1	1
France	1	1
Greece	1	
Iceland	1	
Indonesia		4
Italy	2	2
Japan	1	
Mexico	2	2
New Zealand	4	29
Philippines		1
Portugal	1	1
Turkey	1	
United States	16	13
	35	55

Participants

October 1973 Expert Planning Meeting

Nationalities of Participants	Name	Organization
Canada	Alan Jessop	Geothermal Research Center Department of Energy, Mines and Resources
	Donald Quinsey	Intergovernmental Group Department of Energy, Mines and Resources
	S. A. Gitterman	Central Mortgage and Housing Authority
	J. G. Souther	Department of Energy, Mines and Resources
Federal Republic of Germany	Oskar Kappelmeyer	Federal Institute for Soil Research
France	Paul Sangnier	Délégation Générale à la Recherche Scientifique et Technique
Greece	P. E. Gounaris	Public Power Corporation
Iceland	Karl Ragnars	Department of Natural Heat National Energy Authority
Italy	Pietro Ceron	Ente Nazionale dell'Energia Elettrica, Geothermal Center
	Ezio Tongiorgi	International Institute for Geothermal Research
Japan	Kenzo Baba	Geological Survey of Japan
Mexico	Jorge Guiza	Department of Geothermic Resources, Comisión Federal de Electricidad
	Bernardo Dominguez	Mexicali Office, Comisión Federal de Electricidad
New Zealand	W. D. Stilwell	Ministry of Works Development
	A. J. Ellis	Department of Scientific and Industrial Research
	Robert Kingston	Kingston, Reynolds, Thom and Allardice
	Ken Seal	Geothermal N. Z. Ltd., National Development Council
Portugal	Alfredo Simoes Mendes	National Meteorological Service

October 1973 Expert Planning Meeting

Nationalities of Participants	Name	Organization
Turkey	Sadrettin Alpan	Mineral Research and Study Institute Ministry of Energy and Natural Resources
United States	Rudolph Black	Advanced Research Projects Agency, Department of Defense
	Slator Blakiston	Department of State
	Justin Bloom	Department of State
	James B. Combs	University of California at Riverside
	Gordon Eaton	Department of Interior
	Robert Fournier	U. S. Geological Survey (USGS), Menlo Park
	Stephen Gage	Council on Environmental Quality
	F. S. M. Hodsoll	Executive Office of the President
	Glenn Kendall	Environmental Protection Agency
	William Klostermeyer	Bureau of Reclamation/Department of Interior
	L. J. Patrick Muffler	USGS
	Andre Simonpietri	American Embassy, Mexico
	Raymond L. Zahradnik	National Science Foundation
	John H. Howard	Lawrence Livermore Laboratory
	James C. Bresee	Atomic Energy Commission
	Jack Vanderryn	Atomic Energy Commission
European Communities Commission	Leon Valete	Directorate General for Research, Science and Education
United Nations	Joseph Barnea	U. N. Development Program

Participants

First Geothermal Implementation Conference, New Zealand
April 29-May 3, 1974*

Nationalities of Participants	Name	Organization
Canada	A. M. Jessop	Department of Energy, Mines and Resources
Federal Republic of Germany	G. De Lisle	Federal Institute for Soil Research
France	P. Sangnier	Délégation Générale à la Recherche Scientifique et Technique
Indonesia	H. Djajadi	Geological Survey of Indonesia
	A. Trisulo	Director of Exploration and Production, Pertamina
	Ismet Akil	Geothermal Division, Pertamina
	E. Wishnu	Geological Survey of Indonesia
Italy	E. Tongiorgi	International Institute for Geothermal Research
	E. Stefanelli	Computation Center, Pisa University
Mexico	J. Guiza	Comisión Federal de Electricidad
	B. Dominguez	Comisión Federal de Electricidad
New Zealand	Hon. C. J. Moyle	Minister of Science
	A. J. Ellis	Department of Scientific and Industrial Research (DSIR)
	J. P. M. Bailey	DSIR, Chemistry Division
	W. R. Braithwaite	DSIR, Chemistry Division
	R. B. Glover	DSIR, Chemistry Division
	C. R. James	DSIR, Chemistry Division
	W. A. J. Mahon	DSIR, Chemistry Division
	T. Marshall	DSIR, Chemistry Division
	R. Axtmann	DSIR, Physics and Engineering Laboratory/Princeton U.
	I. G. Donaldson	DSIR, Physics and Engineering Laboratory
	G. R. Katzer	DSIR, Physics and Engineering Laboratory
	G. F. Risk	DSIR, Geophysics Division
	J. R. Hulston	DSIR, Inst. of Nuclear Sciences
	J. Healy	DSIR, Geological Survey

* The Computer-Based Information Systems Substudy was initiated at this conference.

First Geothermal Implementation Conference, New Zealand
April 29-May 3, 1974

Nationalities of Participants	Name	Organization
New Zealand	D. C. Marshall	DSIR, Auckland Industrial Development Division
	R. A. Wooding	DSIR, Applied Mathematics Division
	F. E. Studt	DSIR, Head Office
	J. T. Lumb	DSIR, Head Office
	P. D. Monin	DSIR, Head Office
	K. Lowe	DSIR, Head office
	E. L. D. Fooks	Ministry of Works and Development (MWD)
	G. W. Hitchcock	MWD
	J. V. Robinson	MWD
	W. D. Stilwell	MWD
	D. M. Wigley	MWD
	A. Geelen	New Zealand Electricity Department
	J. Giradin	New Zealand Electricity Department
	M. J. Suggate	New Zealand Electricity Department
	A. H. Cook	New Zealand Ministry of Foreign Affairs
Turkey	Ethem Tan	Mineral Research and Exploration Institute
Philippines	A. Alcaraz	National Power Corporation
United States	J. C. Bresee	Atomic Energy Commission (AEC)
	L. O. Beaulaurier	Bechtel Corporation
	J. Calkins	U.S. Geological Survey (USGS)
	A. L. Clark	USGS
	R. O. Fournier	USGS
	J. H. Howard	Lawrence Livermore Laboratory
	W. C. Klostermeyer	U.S. Bureau of Reclamation
	R. H. Long	National Science Foundation
	F. C. Miller	Stanford University
	W. E. Ogle	AEC (consultant)
	J. T. Schollaert	State Department
	P. A. Witherspoon	Lawrence Berkeley Laboratory
	T. Wadja	U.S. Embassy, New Zealand

PARTICIPATION IN DIRECT APPLICATION OF GEOTHERMAL ENERGY SUBSTUDY

Nationalities of Participants	Paris 6/75	Howard Report 10/75	Paris 6/76	Washington 6/77
Canada		1	1	1
Federal Republic of Germany	1	1	1	1
France	4	1	19	2
Greece			1	
Hungary	1			
Iceland		2	2	1
Indonesia				1
Ireland			1	
Italy	2	3	2	
Mexico		1		
Netherlands			2	
New Zealand		2		1
Nicaragua				1
Philippines		1		
Portugal			1	
Spain	1		1	
Switzerland			1	
Turkey		2		1
United Kingdom	1		2	1
United States	4	15	6	26
	14	29	40	36

Participants

Principal Contributors to NATO-CCMS Report #40
(Non-Electric Status Report)

Nationalities of Participants	Name	Organization
Canada	Alan Jessop	Department of Energy, Mines and Research
Federal Republic of Germany	Oskar Kappelmayer	Geological Survey
France	Paul Sangnier	Délégation Générale à la Recherche Scientifique et Technique
Iceland	Karl Ragnars	National Energy Authority
	Sverrir Thorhallson	National Energy Authority
Italy	Enrico Barbier	International Institute for Geothermal Research
	Mario Fanelli	IIGR
	Ezio Tongiorgi	IIGR
Mexico	Jorge Guiza	Comisión Federal de Electricidad
New Zealand	W. Basil Stilwell	Ministry of Works
	Frank Studt	Department of Scientific and Industrial Research
Philippines	A. Alcaraz	National Power Corporation
Turkey	Sadrettin Alpan	Mineral Research and Exploration Institute
	Ethem Tan	Mineral Research and Exploration Institute
United States	Christopher Barton	Yale University
	Gunnar Bodvarsson	Oregon State University
	L. Boersma	Oregon State University
	G. E. Brandvold	Sandia Laboratories
	James C. Bresee	U. S. Energy Research and Development Administration (ERDA)
	J. J. Cohen	Lawrence Livermore Laboratory (LLL)
	N. B. Crow	LLL
	J. H. Howard	LLL
	Jay F. Kunze	Idaho National Engineering Laboratory
	B. C. Marshall	Sandia Laboratories
	William E. Ogle	ERDA
	Gordon M. Reistad	Oregon State University
	K. B. Tonnesson	University of North Carolina, Chapel Hill
	D. F. Towse	LLL
	Louis B. Werner	ERDA

Direct Applications of Geothermal Energy Substudy

Participants

Paris Non-Electrical Project Meeting, June 25, 1975

Nationalities of Participants	Name	Organization
Federal Republic of Germany	Oskar Kappelmeyer	Geological Survey of Germany
France	Paul Sangnier	Délégation Générale à la Recherche Scientifique et Technique (DGRST)
	Jean Goguel	Bureau de Recherches Géologiques et Minières (BRGM)
	Brigitte Lepeltier	DGRST
	Alain Gringarten	BRGM
Hungary	F. Pickler	State Office of Technical Development
Italy	Mario Fanelli	International Institute for Geothermal Research (IIGR)
	Enrico Barbier	IIRG
Spain	Fernando Pendas Fernandez	E. N. Adaro
United Kingdom	John D. Garnish	Energy Technology Support Unit, U. K. Department of Energy
United States	Jay F. Kunze	Idaho National Engineering Laboratory
	J. H. Howard	Lawrence Livermore Laboratory
	C. H. Bloomster	Battelle Pacific Northwest Laboratory
	M. Coogan	American Embassy, Paris
NATO	Cameron Sanders	CCMS Office

Participants

Paris Meeting, June 9-10, 1976

Nationalities of Participants	Name	Organization
Canada	M. A. Jessop	Department of Energy, Mines and Research
Federal Republic of Germany	O. Kappelmeyer	Geological Survey
France	P. Sangnier	Délégation Générale à la Recherche Scientifique et Technique (DGRST)
	R. Aureille	Electricité de France (EDF)
	P. Boschetti	Ministère de l'Industrie Direction des Mines
	J. Chabal	CFP
	S. Fabrega	Centre d'Etudes Nucléaires
	J. Goguel	Bureau de Recherches Géologiques et Minières (BRGM)
	A. C. Gringarten	BRGM
	B. Housse	ELF-Aquitaine
	M. Jaud	EDF
	J. Lavigne	BRGM
	B. Lepeltier	DGRST
	P. Lessieur	CFP
	M. Maget	BRGM
	G. de Marsily	Ecole des Mines de Paris
	C. Nowakowski	OET-INFRATEL
	J. Olivet	PARICA
	E. Rihard	DGRST
	J. Varet	Université de Paris-Sud
	M. Villaume	OET-INFRATEL
Greece	P. E. Gounaris	Public Power Corporation
Iceland	Thoroddup Sigurdsson	
	G. Palmason	National Energy Authority
Ireland	C. Aldwell	Geological Survey
Italy	C. Corvi	Ministry of Research
	C. Sbarra	Ente Nazionale dell'Energia Elettrica
Netherlands	R. Van Der Wart	Reactor Centrum Nederland
	M. Smeulders	Ministry of Economic Affairs
Portugal	L. Mendes-Victor	Geophysical Institute, R. Escola Politechnica

Paris Meeting, June 9-10, 1976

Nationalities of Participants	Name	Organization
Spain	J. M. Fuster	CSTC, Universidad Complutense
Switzerland	F. Jaffe	Department of Mineralogy
United Kingdom	W. Bullerwell	Institute of Geological Sciences
	J. D. Garnish	Energy Technology Support Unit, UK Department of Energy
United States	D. H. Bloomster	Battelle Pacific NW Laboratory
	J. M. Coogan	American Embassy, Paris
	S. Larsen	Department of Interior
	E. Maust	Bureau of Mines
	J. F. Kunze	Idaho National Engineering Laboratory
	E. H. Willis	Energy Research and Development Administration
EURAFREP	J. P. Munier-Jolain	
European Communities Commission	E. Staroste	
	H. Marchandise	

Participants

Conference on Economics of Direct Uses of Geothermal Energy
Washington, D.C., June 21-22, 1977

DELEGATES

Nationalities of Participants	Name	Organization
Canada	Alan Jessop	Department of Energy, Mines and Resources
Federal Republic of Germany	Oskar Kappelmeyer	Geological Survey
France	Paul Sangnier	Délégation Générale à la Recherche Scientifique et Technique (DGRST)
	Roger Aureille	Electricité de France
Iceland	Karl Ragnars	National Energy Authority
Indonesia	W. Subroto Modjo	Ministry of Mining
Italy		
New Zealand	John Boshier	New Zealand Electric Department
Nicaragua	Roberto Vega	National Light and Power Company
Turkey	Sadrettin Alpan	Mineral Research and Exploration Institute
United Kingdom	J. Garnish	Energy Technology Support Unit, U. K. Department of Energy
United States	Clem Bloomster	Battelle Pacific NW Laboratories
	James Bresee	U. S. Energy Research and Development Administration (ERDA)
	Marilyn Eggers	ERDA
	S. F. Fogleman	International Engineers, Inc.
	Robert Forbes	University of Alaska
	Tex Harris	Environmental Protection Agency
	C. D. Hornburg	DSS Engineers, Inc.
	W. E. Johnson	WESTEC Services, Inc.
	John Karkheck	Brookhaven National Laboratory
	J. F. Kunze	Idaho National Engineering Laboratory
	Tod Larson	University of California, Riverside
	W. W. S. Yen	Lawrence Berkeley Laboratory

PARTICIPATION IN RESERVOIR ASSESSMENT SUBSTUDY

Geothermal Fluid Injection

Nationalities of Participants	Wairakei 1st Meeting	Japanese Meeting 12/74	El Centro 2nd Meeting	Taupo 3rd Meeting
El Salvador			1	1
France			1	1
Italy				1
Japan		14		
Mexico				2
New Zealand	17		4	17
Philippines			1	2
Turkey				1
United States	3	6	7	7
	20	20	14	32

Participants

First Workshop on Geothermal Fluid Injection, Wairakei, New Zealand
November 18-27, 1974

Nationalities of Participants	Name	Organization
New Zealand	P. F. Bixley	Ministry of Works and Development (MWD)
	R. S. Bolton	MWD
	P. R. L. Browne	Department of Scientific and Industrial Research (DSIR)
	N. D. Dench	MWD
	I. G. Donaldson	DSIR
	E. L. D. Fooks	DSIR
	R. B. Glover	MWD
	G. S. Harris	N. Z. Energy R&D Committee
	G. W. Grindley	DSIR
	G. W. Hitchcock	DSIR
	J. T. Lumb	DSIR
	A. McNabb	DSIR
	P. M. Otway	DSIR
	H. P. Rothbaum	DSIR
	W. B. Stilwell	MWD
	F. E. Studt	DSIR
	D. M. Wigley	MWD
United States	T. E. Backstrom	U.S. Bureau of Reclamation (USBR)
	W. A. Fernelius	USBR
	M. K. Fulcher	USBR

Reservoir Assessment Substudy

Participants

Japanese Geothermal Injection Meetings, December 2-6, 1974

Nationalities of Participants	Name	Organization
Japan	Ko Takeda	Ministry of International Trade and Industry
	Kozo Esaki	Ministry of International Trade and Industry
	S. Sakakura	Ministry of International Trade and Industry
	Hideo Iga	Japanese Geothermal Energy Association
	M. Yora	Mitsubishi Metal Corporation
	Tadasuki Nakashima	Kyushu Electric Power Company, Inc.
	Katsundo Kubota	Kyushu Electric Power Company, Inc.
	Yasuhiko Ejima	Kyushu Electric Power Company, Inc.
	Hideo Ysautaki	Kyushu Electric Power Company, Inc.
	Kenjiro Yanagese	Kyushu Electric Power Company, Inc.
	Tsuneo Uemura	Kyushu Electric Power Company, Inc.
	Junji Suyama	Geological Survey of Japan
	Kiyoshi Sumi	Geological Survey of Japan
	Kenzo Baba	Geological Survey of Japan
United States	Dr. William Ogle	Atomic Energy Commission (AEC)
	William W. Henoch	AEC Scientific Representative
	Myron B. Kratzer	U. S. Embassy, Tokyo
	Douglas B. McNeal	U. S. Embassy, Tokyo
	Spenser Richardson	U. S. Embassy, Fukuoka
	Masaaki Hashimoto	U. S. Embassy, Fukuoka

Participants

Second Geothermal Workshop on the Injection of Geothermal Brines,
El Centro, May 15-17, 1975

Nationalities of Participants	Name	Organization
El Salvador	Gustavo Cuellar	CEL Laboratorio Geotérmico
France	Alain Gringarten	Bureau de Recherches Géologiques et Minières
New Zealand	R. S. Bolton	Ministry of Works and Development (MWD)
	W. J. P. McDonald	
	W. B. Stilwell	MWD
	F. E. Studt	Department of Scientific and Industrial Research (DSIR)
Philippines	Arturo Alcaraz	National Power Corporation
United States	Ed Backstrom	Bureau of Reclamation, Denver
	Jerry Dodd	Bureau of Reclamation, Denver
	W. A. Fernelius	Bureau of Reclamation, Boulder City, Nevada
	M. K. Fulcher	Bureau of Reclamation, Boulder City, Nevada
	R. T. Littleton	Bureau of Reclamation, Boulder City, Nevada
	K. E. Mathias	Bureau of Reclamation, Boulder City, Nevada
	George Talbott	Bureau of Reclamation, Denver

Participants

Third Injection Workshop, Taupo, New Zealand
September 4-5, 1976

Nationalities of Participants	Name	Organization
El Salvador	G. Cuellar	CEL Laboratorio Geotérmico
France	A. C. Gringarten	Bureau de Recherches Géologiques et Minières
Italy	G. Manetti	Ente Nazionale dell'Energia Elettrica
Mexico	Jesus Rivera	Comisión Federal de Electricidad (CFE)
	Enrique Tolivia	CFE
New Zealand	P. F. Bixley	Ministry of Works and Development (MWD)
	R. S. Bolton	MWD
	P. R. L. Browne	New Zealand Geological Survey (NZGS)
	E. L. D. Fooks	MWD
	R. B. Glover	Department of Scientific and Industrial Research (DSIR)
	J. Healy	NZGS
	G. W. Hitchcock	MWD
	Ian Innes	MWD
	Russell James	DSIR
	W. A. J. Mahon	DSIR
	P. MacDonald	Geophysics Division
	A. McNabb	Applied Mathematics Division
	Ian Nairn	NZGS
	Peter Otway	NZGS
	K. E. Seal	Ceramco
	W. B. Stilwell	MWD
	F. E. Studt	DSIR
Philippines	Arturo Alcaraz	National Power Corporation
	Chester F. Budd	Union Oil/Phil. Geothermal, Inc.
Turkey	Mehmet Saltuklaroglu	
United States	M. K. Fulcher	U. S. Bureau of Reclamation (USBR)
	M. S. Gulati	Union Oil
	S. Larsen	USBR
	K. E. Mathias	USBR
	H. J. Ramey	Stanford University
	R. N. Upadhyay	Union Oil
	P. A. Witherspoon	Lawrence Berkeley Laboratory

SMALL POWER PLANTS SUBSTUDY

Nationalities of Participants	Berkeley Meeting June 1975	Azores Meeting September 1975
El Salvador	1	
Federal Republic of Germany	1	
France	1	3
Haiti	2	1
Iceland	3	
Italy	2	
Japan	4	
Kenya	1	
Mexico	2	
New Zealand	3	
Nicaragua	2	1
Philippines	1	
Portugal	3	2+
United Kingdom	2	1
United States	19	13
Yugoslavia		1
	47	22+

Small Power Plants Substudy

Participants

Attendees, Small Power Plants Conference, Berkeley, California
June 2, 1975

Nationalities of Participants	Name	Organization
El Salvador	Gustavo Cuellar	Comisión Ejecutiva Hidroelectrica del Rio Lempo
Federal Republic Germany	Eckart Langeluddecke	Dornier System Gmbh
France	Alain C. Gringarten	Bureau de Recherches Géologiques et Minières
Haiti	Alix Cameau	Electricité d' Haiti
	Andre E. Wainright	Electricité d' Haiti
Iceland	Valdimar K. Jonsson	University of Iceland
	Karl Ragnars	National Energy Authority
	Sverrir Thorhallsson	National Energy Authority
Italy	Enrico Barbier	International Institute for Geothermal Research
Japan	Kentaro Aikawa	Mitsubishi Heavy Industries
	Shobu Hasegawa	
	Hisashi Ohtsuka	Toshiba International Corporation
	Yoji Sato	Dowa Mining Co., Ltd.
Kenya	Sebastian Bwire-Ojiambo	Geothermal Projects
Mexico	Jorge Guiza	Comisión Federal de Electricidad
	Sergio Mercado	Comisión Federal de Electricidad
New Zealand	R. S. Bolton	Ministry of Works and Development
	W. Basil Stilwell	Ministry of Works and Development
	Franke E. Studt	Department of Scientific and Industrial Research
Nicaragua	Roger Arcia	Empreso Nacional de Luz y Fuerza
	Ariel Zuniga	
Philippines	Arturo Alcaraz	National Power Corporation
Portugal	Victor H. Forjaz	Faculty of Sciences
	Luis Mendes-Victor	Faculty of Sciences
	Julio Quintino	Observatorio "Afonsa Chaves," Azores

Attendees, Small Power Plants Conference, Berkeley, California
June 2, 1975

Nationalities of Participants	Name	Organization
United Kingdom	Derek Marriott	Eng. and Power Development, Consultants
	J. R. Shaw	Merz and McLellan
United States	William R. Austen	Naval Facilities Systems Command
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	James T. Kuwada	Rogers Engineering Co., Inc.
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	William Ogle	ERDA
	Lila Smith	ERDA
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*Names of additional Portuguese participants will be available in the procedings of the Azores Meeting to be published by the Azores Earth Sciences Institute.

HOT DRY ROCK CONCEPTS SUBSTUDY

Nationalities of Participants	1st Meeting LASL 1974	2nd Meeting LASL 1977
Canada	1	
Egypt		1
Federal Republic of Germany	2	3
France	3	2
Indonesia		1
Italy	3	1
New Zealand	1	
Nicaragua	1	
Sweden	3	4
Switzerland		1
Turkey	1	
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	95	85

Hot Dry Rock Concepts Substudy

Participants

Information Meeting, Los Alamos Scientific Laboratory
September 17-19, 1974

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Information Meeting, Los Alamos Scientific Laboratory
September 17-19, 1974

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Information Meeting, Los Alamos Scientific Laboratory
September 17-19, 1974

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Hot Dry Rock Concepts Substudy

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Hot Dry Rock Concepts Substudy

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Hot Dry Rock Concepts Substudy

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APPENDIX 2. STATUS OF SELECTED GEOTHERMAL PROGRAMS THROUGHOUT THE WORLD

INTRODUCTION

The following is a summary of the status of the geothermal programs of those countries that have actively contributed to the CCMS geothermal program. Information was drawn from United Nations and CCMS conference proceedings, correspondence with U.S. State Department Science Attaches, discussions with experts who have traveled to the various countries, journal articles, pamphlets and speeches. Comments, criticism and additional information are welcome at any time and may be sent to the Office of International Programs, International Affairs, U.S. Department of Energy, Washington, D.C. 20545, USA.

CANADA

A program for geothermal research and development was initiated by the Canadian Department of Energy, Mines and Resources (EMR) in 1975. Up to that time, only chemical analysis of hot spring waters and a small drilling program at the Meager Creek Hot Springs had been attempted. New funds at an initial level of $100,000 appeared in 1976, and EMR began the assessment of the geothermal potential of the cordillera of British Columbia and the Yukon, the most promising areas in Canada. The potential of the areas is still unknown, but there are several promising sites. Unfortunately, many of these are in very isolated and mountainous country.

EMR and the British Hydro and Power Authority are cooperating in the assessment of the Meager Mountain site, about 100 miles north of Vancouver. It is hoped that it will be possible to define a target for a deep exploratory well within two years.

The other promising areas for geothermal development in Canada are the sedimentary basins of the Prairie Provinces, especially for near-term development. The EMR program statement estimated in 1976 that the Prairie Provinces had heat reserves of approximately 4.8×10^{22} J at a threshold temperature of 50°C, and EMR feels that by 1985 a 10 MWt (3.2×10^{14} J/year) heat capability could be established for the heating of large buildings. A deep well will be drilled at Regina during 1978 to provide confirmation of projected geological data and to form the producing well of a doublet after the French style.

The only current use of geothermal energy in Canada is in the city of Whitehorse in the Yukon. The city mixes (7°C) spring water flowing at a rate of 2,000 gal/min with local surface water to keep the city's water supply from freezing. Some hot springs are used to warm swimming pools throughout the cordillera.

EL SALVADOR

The Comisión Ejecutiva Hidroelectrica del Rio Lempa (CEL) is responsible for developing El Salvador's geothermal potential, and will spend more than $35 million over the five-year period between 1976 and 1980. The United Nations spent $2 million in the early 1970's to explore the Ahuachapan geothermal field, a major power producer for El Salvador. Two 30-MWe units at Ahuachapan are now

operating and along with El Salvador's hydroelectric resources, make the country self-sufficient in the production of electricity. In 1979 a third and final unit of approximately 35 MWe will be added to complete the field's currently projected capacity. Waste geothermal fluids are injected. A French drilling company, FORAMINES, is drilling exploratory wells in San Vincente and Usulutan Province for additional geothermal capacity.

FRANCE

Four organizations support geothermal energy research, development and demonstration in France. The Délégation Générale á la Recherche Scientifique et Technique (General Delegation of Scientific and Technical Research) has broad responsibility for energy matters in France. The Bureau de Recherches Géologiques et Minières has assessed and inventoried the low enthalpy resources of France. In 1977, the Institut National Astronomique et Géologique started a geophysical research program on hot dry rock, so far only in the paper-study phase. In 1977, the European Community funded a two-year experimental program in France to increase rock permeability by chemical leaching.

Geothermal development in France is primarily in the Paris Basin. This area was thoroughly explored geologically from 1950 to 1965, when about 2,000 exploratory oil wells were drilled, only a handful of which were productive. Numerous deep aquifers were found, though, conveniently located near population centers and at temperatures high enough for space heating. There are now four regions around Paris with geothermal heating systems in various stages of development and installation.

The largest heating system is at Creil, twenty-five miles north of Paris. This system began to serve 2,000 apartments in the fall of 1976 and will eventually supply heat to 4,000 apartments. The system consists of two extraction wells (each with a downhole pump), and two reinjection holes; water temperature is around 57°C. Three heat pumps are used in addition to heat exchangers to increase the system's efficiency. Electricité de France has instrumented the Creil system to monitor performance throughout the heating season in order to compare the actual performance and economies with the design projections. So far, geothermal energy has accounted for over 40 percent of the heating requirement of the apartments.

Melun, twenty-five miles southeast of Paris, is the site of a large geothermal heating system which is currently being retrofitted to 4,000 apartments. Two whipstock holes, 1,800 m deep and separated by 900 m at the bottom, supply the system, which is supplemented by conventional heating in colder months.

The two other geothermal heating systems in the Paris region are Villeneuve-La-Garenne where 1,700 apartments are being installed with facilities similar to Creil's, and Mee-sur-Seine, where 6,000 apartments and 50,000 square meters of office space are to receive 70 percent of their heating requirements from geothermal energy.

FEDERAL REPUBLIC OF GERMANY

The Bundesministerium für Forschung und Technologie (BMFT) funds geothermal research and development in West Germany as part of the German national energy program. The Project Management for Energy Research in KFA-Jülich is responsible for geothermal development in Germany. The

European Community also sponsors research in the Federal Republic related to geothermal energy.

The Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and the Niedersachsisches Landesamt für Bodenferschung (NLfB), both in Hanover, completed a geothermal map of the country in early 1978. Ochtendung is the site of a 700 m borehole within the Eifel Mountains which was drilled in order to investigate the geothermal situation of the western part of the Eifel. A negative geothermal anomaly was found there.

Germany has a poor hydrothermal resource base. There are only two areas with some potential for development. The first is the Landau area of the Upper Rhine Valley where a temperature anomaly was found but the low permeability and temperature of the rock has so far prevented economical exploitation. The second is the Urach area southwest of the Stuttgart where a test drilling discovered water temperatures around 100°C at 2000 m; 150°C is expected at 3500 m. A single borehole, man-made geothermal energy system is to be tested in the Urach borehole in summer 1978.

The BGR is currently attempting to connect horizontally several 260-m deep boreholes spaced about 100 m apart by means of hydraulic fracturing in the Bayrischer Wald Mountains. If the connection is successful, flow experiments will be started to study heat exchange processes in a fracture system.

The Federal Republic also conducts work supporting geothermal development in deep drilling technology for natural gas wells, rotary high speed drilling, and binary cycles as part of a solar program.

GREECE

The two leading organizations responsible for developing the geothermal resources of Greece are the Public Power Corporation (PPC) and the Institute of Geological and Mineral Research (IGMR). The PCC is a quasi-governmental agency that manages and finances deep drilling and related surveys. In May 1977, PPC signed an agreement with the Italian State Energy Agency, ENEL, to have them furnish technical assistance to PCC for the development of geothermal energy on Milos Island, and to carry out surveys in other promising areas in Greece. IGMR conducts soil investigations, geological, hydrogeological, and geochemical surveys, shallow drillings, temperature measurements, and other preliminary surveys. The IGMR is a quasi-government agency like PPC, financed by the Greek government, and receives an appropriation of approximately $27,000 annually for its program of geothermal surveys.

Greece is proceeding slowly in the development of its geothermal resources because of its limited geothermal potential, which has been utilized only for resort and therapeutic baths. Geothermal exploration in Greece was assisted by a 1970 OECD grant to the Italian International Institute for Geothermal Research (IGMR) in Pisa to conduct a geochemical survey in Greece. Six areas were identified by IGMR, the most promising being Milos, Lesbos Islands, and the Sperchios River graben. The PPC has conducted two exploratory drillings in Milos, one of which was put into production to evaluate the geothermal fluid, and it is considering the installation on Milos of two 15-MWe units. However, these units have not yet been included in PPC's ten-year, 1977-86 power development plan.

ICELAND

The organization responsible for developing geothermal resources in Iceland is the National Energy Authority (NEA). The departments chiefly responsible within it are the Department of Natural Heat, State Drilling Contractors, and State Natural Heat Supply. The Reykjavik District Heating Service is independent of the NEA.

Iceland is rich in hydroelectric and geothermal resources. It has an estimated hydro potential of 3 million kW and has harnessed about 10 percent of this resource because the technology is surer and more cost competitive than geothermal. For these reasons, electric power from geothermal resources has not been a major focus of development. However, in places such as the northern parts of Iceland, where there are important environmental concerns or the threat of a river drying up during a prolonged cold spell, electric power from geothermal resources has been introduced.

Most of the geothermal reservoirs now under development are located in the southwest corner of the island on or near the Reykjanes Peninsula or in the north-central part of the island. The high temperature fields are found along the mid-Atlantic volcanic zone, which runs through Iceland.

Iceland uses most of its geothermal resources presently for domestic and industrial heating, where it is most cost effective. At the end of 1976, 130,000 people or 59 percent of the population used geothermal heating; in 1977, 134,000 or 61 percent of the population and, within a few years, the figure may approach 72 to 76 percent of the population.

The Reykjavik District Heating System, fed by the Reykjavik and Reykir geothermal fields on the Reykjanes Peninsula, serves the capital city of Reykjavik and three neighboring towns. Total heat capacity of the system in 1977 was 420 MWt, and it is expected to grow to 520-540 MWt by the end of 1978. In 1976, the system served 110,000 people out of a total population of 113,000. The geothermal water is quite clean and is used directly for bathing, washing and cooking as well as heating. Currently, drilling is under way to the south and west of the city due to concern over draw-down of the geothermal reservoirs serving the system.

The Sudurnes Regional Heating Service on the Reykjanes Peninsula uses the Svartsengi high temperature geothermal field, the first major heating system to use high temperature water. In 1976, 300 homes were connected; ultimately the system will serve 12,000 people and the Keflavik International Airport. The Nejavelliv field, actually the northern part of the Hengill field just east of the Reykjanes Peninsula, may eventually be tied into the Reykjavik heating system. The city of Akureyi, 281 miles northeast of Reykjavik and Iceland's third largest city, has a hot water system similar to Reykjavik's. Recently, it began to serve 1,200 residents and when completed will serve the entire population of 12,000 of the city. The Blondurs District Heating, also in north-central Iceland, is to be operating in the winter of 1978 and will serve about 800 Icelanders.

Electricity is generated in the northern part of the island, at the Namafjall and Krafla high temperature fields. Since 1970, 3 MWe is produced at Namafjall and steam heat is used to dry diatomaceous earth. The Krafla field, located

8 kilometers northeast of Namafjall, was intended to provide geothermal steam to a 55-MWe power plant, which would eventually become part of the Icelandic National Power Grid, at a cost of $40 million. The plant has been built and the two Mitsubishi turbogenerators installed, but the plant is not on-line because of a very unfortunate series of events. In 1974, two exploratory holes of 1,100-m depth revealed temperatures of up to 330°C. On the basis of the promising temperatures and flows encountered, six production holes were drilled. On December 20, 1975, volcanic eruptions occurred one or two miles from the power plant, altering the below-surface heat sources and aquifers. In 1976, there were nine earthquakes of magnitude four or greater on the Richter scale plus many thousands of earth tremors. Corrosive gases found their way into the wells, thereby compounding development problems. In April 1977, several major earth movements and a small volcanic eruption took place and were followed by a volcanic eruption three miles from the Krafla station in September 1977. This last event, which was associated with earthquake activity, damaged the diatomite plant's geothermal reservoirs at Namafjall. In February 1978, NEA, after repairing some wells, was able to begin start-up operations of the plant and to start supplying around 10 MWe to the National Grid. In an effort to get the Krafla power on-line, gravity changes and seismic activity are being recorded, and tilt measurements and chemical analysis of escaping gases are being monitored to determine if the uplifting of the features is due to steam lifting or to magmatic intrusion.

Iceland has made good use of one volcanic eruption. In January 1973, a major volcanic eruption at the edge of a town on the Westman Islands destroyed about one-third of it. As an aid to rebuilding, the latent heat of the lava was tapped and circulated through a pipe grid buried in hot lava, to provide hot water to the town. A pilot installation near lava at 305°C has resulted in hot water production at 190°C.

INDONESIA

Indonesia has considerable geothermal resources, most of which lie along the volcanic belt of the islands. Most exploration has been done in the main islands of Java and Bali, but the greatest potential appears to be in the densely populated outer islands. Early exploration efforts received assistance from the U.S. Agency for International Development and the United Nations Educational, Scientific, and Cultural Organization.

The Geothermal Section of Indonesia's Geological Survey has the main responsibility for exploration and development; it has worked with the Scripps Institute of Oceanography, Union Oil Company of the United States, and with the University of Tokyo. The Geology Division of Pertamina, the state-owned oil company, has investigated the North Banten area of northwestern Java. Pertamina hopes to do more geothermal work when monies become available.

The Komajong solfataric field in West Java is the most developed geothermal site in Indonesia. Deep exploratory drilling was completed in 1974 and the government is considering installation of a 30-MWe power plant there, possibly beginning as early as late 1978. New Zealand is supplying technical and financial assistance for this project.

Other geothermal sites in various stages of exploration or development are the Dieng-plateau field in Central Java, where extensive drilling found waters with temperatures up to 173°C; Salak, Palabukan-Ratu and Bantan, all in West Java; and the island of Sumatra, where a 13-MWe plant is under development.

ITALY

The Ente Nazionale per l'Energia Elettrica (ENEL), the Italian State Utility, develops the geothermal resources in Italy through its Geothermal Research Center. This center employs 500 people and had a 1977 budget for geothermal energy of approximately $16.9 million. In 1977, ENEL entered into a joint venture with AGIP, the Italian State Oil Company, for the exploration of new geothermal resources in Italy. The Consiglio Nazionale delle Ricerche (CNR) conducts geothermal research through its International Institute of Geothermal Research in Pisa, which has a budget of about $395,000 for 1977. The CNR also has a special energy program under way that has allotted $4 million to geothermal research over a five-year period.

The ENEL operates a total installed geothermal electrical capacity of 421.5 MWe, which produces 2.5 GWh yearly or approximately 1.7 percent of the national annual electricity production. The ENEL plans to install by 1980 an additional 40 MWe. Direct uses, such as greenhouse or district heating in Padua and Larderello, are conducted primarily through the private sector in Italy.

All of the Italian geothermal fields under exploitation or exploration lie along the pre-Apennine belt stretching from Pisa past Rome to Naples. New geothermal fields were found at Travale, Alfina and Cesano after the 1973 oil crisis. Today, ENEL is developing the Larderello, Travale, Bagnore and Piancastagnaio fields and is still exploring the Alfina and Cesano areas.

Larderello, the oldest developed geothermal field in the world, has over 400 exploitation wells distributed over an area of almost 200 km^2. These wells have an average depth of 668 m and the depth extends down 2,703 m. The ENEL is continually drilling new wells to compensate for the decreased productivity of existing wells. Today, the producing area of Larderello is 60 km^2.

At Larderello, as well as at Travale, ENEL is beginning to implement a stimulation program to recover heat either by artificially increasing rock permeability or by producing fractures to connect the unproductive wells to neighboring permeable formations. The ENEL is currently concentrating on hydraulic fracturing of low producing wells with both high temperature and low permeability at Larderello. It is also planning a project where it will drill below the producing zone of Larderello, down to 5,000 m, in an effort to investigate any rock formations that, when fractured, might form a reservoir different from the one presently exploited. Currently, ENEL is selecting techniques and conducting limited field experiments with full field work on this project to begin in late 1978.

The Travale field is much smaller than Larderello, with 19 producing wells spread over a 10 km^2 area. The actual producing area is only 2 km^2. In 1977, ENEL began studying possibilities for stimulating unproductive wells by hydraulic fracturing and cyclic pressure impulses.

The other developed fields are Bagnore and Piancastagnaio, near

Mount Amiata, and they have been generating power for over fifteen years. The small (2 km^2), low temperature steam field, Bagnore, is southwest of Mount Amiata. Its thirteen productive wells (average depth 768 m) supply two small (3.5 MWe) generators that discharge directly to the atmosphere because of the high (7-8 percent) concentration of noncondensable gases. The Piancastagnaio field is just southeast of Mount Amiata. Nineteen wells, with an average depth of 773 m, are distributed over a 5 km^2 productive area. They supply 180°C steam to a 15-MWe turbogenerator which exhausts directly to the atmosphere due to a 21 percent concentration of noncondensable gases in the geothermal fluid. The ENEL has drilled fourteen wells to an average depth of 1,054 m in the 12-km^2 Alfina field. Temperatures of up to 150°C have been encountered in fluid containing 7,000 ppm dissolved solids. In February 1977, ENEL conducted a successful hydraulic fracturing and acidification experiment on a well and increased its capacity by a factor of six. The ENEL is studying the possibility of using Alfina for the generation of electricity with reinjection of the geothermal fluid to contain pollutants.

Exploratory drilling of the Cesano field, 20 km north of Rome, started in 1973. The first well found a hot (maximum temperature of 285°C), supersaline (total dissolved solid of 350,000 ppm) fluid, but three additional wells, drilled about 700 m from the producing wells, produced nothing due to very low permeability of the formation. An injection well was drilled 2 km from the discovery well, and an acidizing treatment was successful in increasing the original low permeability. The Cesano area measures about 2 km^2, and wells average 2,180 m in depth. The ENEL is considering Cesano as a research site for future stimulation studies.

MEXICO

The Comisión Federal de Electricidad (CFE) is responsible for the development and utilization of Mexico's geothermal resources which are used principally for electricity generation. The CFE began exploration of Mexico's geothermal potential in 1960, and with assistance from New Zealand developed the field at Cerro Prieto (twenty miles south of Mexicali on the California-Mexico border) where it built a 75-MWe power plant. Extensive investigations are also under way at Los Azufres, where exploratory drilling started in 1977, at Ixtalan de los Hervores, and Los Negritos, all located northwest of Mexico City.

Cerro Prieto is the site of a 75-MWe plant that began operation in November 1973. Fifteen wells, drilled to depths of 900-1,500 m, supply two turbines. The field is water-dominated, but very hot, with the highest temperature measured at 340°C. The geothermal fluid is disposed of in a dry lake bed; injection is under study since some subsidence has taken place, on the order of 30 cm. Currently, CFE is drilling new wells to expand power output of the plant to 150 MWe. The field may eventually support 400 MWe which would require the drilling of fifty-five new wells.

In 1977, the U.S. Department of Energy and CFE signed a five-year agreement to undertake a program of cooperative investigation of the Cerro Prieto field. The investigations will allow experts from both countries to understand better the Cerro Prieto and neighboring geothermal fields of the Imperial Valley in California. (For a

description of the Joint U.S.-Mexican investigations at Cerro Prieto, see Appendix 3-D.)

NEW ZEALAND

The Ministry of Works and Development, aided by the Department of Science and Industrial Research, controls the development and utilization of geothermal resources in New Zealand. Funding for geothermal investigations in fiscal year 1978 was $4 million and for fiscal year 1979, $6.5 million. Extensive hydroelectric resources, which supply the majority of New Zealand's electricity, and a substantial natural gas field compete with, and have discouraged the development of New Zealand's high quality geothermal resources. Presently, the total installed electric capacity derived from New Zealand's geothermal fields is 202 MWe, supplying over 10 percent of New Zealand's electrical requirements.

The Wairakei field was first brought into operation in 1958. Its rated capacity of 192 MWe supplied 1,250 GWh annually to the national grid, or roughly 8 percent of the grid's requirements.

Most wells at Wairakei are in the range of 2,000-2,500 feet deep, although one exploratory well reaches down to about 7,500 feet. Sixty-one wells supply thirteen plants with steam at two million pounds per hour. Because corrosion is not a factor due to the purity of the steam (>99.9 percent), the plants have a utilization factor of about 90 percent. At present, discussion concerning production at Wairakei is centered on identifying the most satisfactory way in which to maintain output because of substantial drops in steam temperature and pressure. Several outlying wells have been lost due to cooler water encroachment. The ground has subsided as much as several feet over a 1.5-square mile area and some natural geothermal phenomena, such as geysers and fumaroles, have ceased.

Waste water from the geothermal wells at Wairakei is about 4800 tonnes/hour, and reaches the Waikato River at 55°C. The combined cooling water and condensate totals 33,750 tonnes/hour, and is discharged at 33°C. The total increase in river temperature under average flow conditions from waste water, cooling water and condensate is 1.5°C.

In the late 1960's, twenty-five wells were drilled in the Broadlands geothermal field, just northeast of Wairakei, but despite its promise (a high temperature of 300°C), development slowed down following the discovery of a major offshore gas field. The Broadlands field was removed from the New Zealand Power Plan in 1970 but was restored in 1974 when a program of four wells drilled per year was reactivated. An environmental impact report for the Broadlands field has been prepared and public discussion on the report and review will take place shortly. Injection experiments are under way, one at the edge of the field and one at a central location within the field. An alfalfa drying and pelletizing plant also began operation last year.

The Kawerau and Rotorua fields both make contributions to the energy economy of New Zealand. The former provides around 115 tons/hr to various sections of the Tasman Pulp and Paper Company including some for the generation of 10 MW of electricity. The Rotorua field provides 0.2 GWh/year to various customers such as the Queen Elizabeth Hospital and the Rotorua Hotel, which uses it for heating, air conditioning and hot tap water.

New Zealand is also investigating the possibility of geothermal district heating for the City of Auckland. Through bilateral agreements, New Zealand has helped the Philippines, Indonesia and Mexico find and tap their geothermal resources.

NICARAGUA

The Empresa Nacional de Luz y Fuerza (ENALUF), the National Power and Light Company, is responsible for developing the geothermal resources of Nicaragua, and has spent over $12 million in developing the Momotombo geothermal fields. The government agency in charge of supporting research is the Servicio Geological Nacional, the National Geological Service. The Momotombo volcano, 60 km west of Managua, is the most promising site for development. Of the nineteen wells drilled there, six are productive and could support a 30-MWe power plant. The ENALUF plans to let a contract to build a power plant at the Momotombo site in 1978. The only current use of geothermal energy in Nicaragua is for balneological purposes in the hot springs of Tipitapa, 24 km from Managua.

PHILIPPINES

Because the Philippine government is in the process of reorganization, responsibilities of various agencies for development of the geothermal resources of the Philippines are still in a state of flux. However, the national program for geothermal energy development is ambitious and calls for this resource to meet 25 percent of the total energy requirements of the island by 1985. The Philippine National Oil Company-Energy Development Corporation appears to have embarked on a policy of installing small power plants to make use of early wells in advance of developing the entire field for larger, more efficient units, as events on Leyte Island recently showed.

Geothermal development on Leyte is supported by technical assistance from the government of New Zealand. Exploratory drilling performed by Kingston, Reynolds, Thom, and Allardice (KRTA) has encountered temperatures above 300°C at 1900 m, indicating a very promising geothermal field. In July 1977, the Philippine National Power Corporation installed a 3-MWe noncondensing steam turbine at Leyte with assistance from KRTA and the Union Oil Company. The small power plant will service the town of Ornac and the drilling site.

At the Tiwi field in southeastern Luzon, Union Oil has drilled over twenty-one wells for a 110-MWe power plant which is to become operational in 1978. Also, the National Science Development Board has funded a small venture at Tiwi, in which steam from a shallow well (200 m) powers a 2.5-kWe turbine generator set and provides heat for an experimental, combined salt-making and grain-drying system, which has been in operation for several years.

Other geothermal locations are Los Baños, 30 miles outside Manila, where Union Oil has been drilling for a 55-MWe power plant, and Negros Islands, where results of recent drillings have been encouraging for the eventual development of geothermal energy.

PORTUGAL (AZORES)

Geothermal development in the Azores commenced in 1974 with the drilling of an experimental hole by a Canadian drilling team from Dalhousie University and Lamont-Doherty Geological Observatory, which encountered fluid temperatures of 200°C

at roughly 900 m depth on the island of Sao Miguel. In June 1977, Geonomics, Inc. of California started field investigations at the request of the Portuguese government on Sao Miguel to determine the geothermal potential of the area. A system of small power plants is planned (the first one will be 3 MWe) to phase out dependence on hydropower so that the water can be used for irrigation and power plant cooling. Installed capacity for electricity on Sao Miguel was 14.9 MWe in 1975 with a population of 180,000 people. The potential for direct heat applications of geothermal energy in the Azores include food processing (sugar, powdered milk, agar-agar), greenhousing, canning, space heating, and production of fresh water. Portugal has announced plans to establish an experimental geothermal laboratory in connection with the Earth Sciences Institute in the Azores to oversee the development of geothermal energy.

SWEDEN

The National Swedish Board for Energy Source Development organizes and sponsors energy R&D in Sweden and has allotted $1.6 million for a geothermal program starting in 1976 and ending in 1979. The emphasis of the program focused on the development of hot dry rock resources. A team of geologists at Chalmers University in Göteborg has begun a program of prospecting for hot dry rock on the Bohus granites on the Swedish western coast. Thus far, no major heat anomalies have been identified.

SWITZERLAND

The Swiss have conducted a geological survey of their hot dry rock resource potential. The best prospects are found along the Molasse Basin, where most of the population and industry of Switzerland is located and the average temperature at a depth of 5 km is 150°-170°C. Switzerland will not develop these resources independently, but plans to work with other countries to develop the needed technology.

TURKEY

The Mineral Research and Exploration Institute of Turkey (MTA) in Ankara conducts the country's geothermal research and exploration. Based upon the successful operation of a 0.5-MWe pilot plant for the past two years, MTA has under construction a 5-MWe facility at the Kizildere wet-steam field. Maximum temperature recorded is 207°C, but the field has serious problems with calcium carbonate scaling. The MTA is also operating a small (20 m x 50 m) greenhouse at Kizildere.

Two wells drilled near the city of Afyon have encountered temperatures up to 106°C at 905 m. Heat exchanger tests of the geothermal fluids have been completed, and the wells may be used to help supply heat to the city for space and hot water heating. The MTA is also conducting preliminary investigations to evaluate potential of the Cappadoccian caldera in central Anatolia for hot dry rock development.

UNITED KINGDOM

In 1976 the Energy Technology Support Unit, Harwell, prepared a report for the United Kingdom Department of Energy entitled "Geothermal Energy: The Case for Research in the United Kingdom," which concluded that although the outlook for geothermal utilization in the United Kingdom is not too promising, the government should initiate a geological survey of possible areas and a market analysis for their heat. The United Kingdom Department of Energy therefore funded a $1.5 million, three-year program

in 1976 to determine the hot water and hot rock potential of the United Kingdom. The work is carried out by the Institute of Geological Sciences and several university departments. Promising early results have led to proposals for expanded effort in selected areas, notably the sedimentary basins in southern and western England and in southern Scotland. Hot aquifers already identified will receive further attention to see if they can be exploited in the same way as in the Paris Basin in France. Anomalously high heat flows have been confirmed in the granites of SW England, where gradients around 40°C/km are observed. Camborne School of Mines is investigating the possibility of heat recovery. Other igneous areas will be investigated later.

All this work receives support from the European Community.

UNITED STATES OF AMERICA

The United States has a comprehensive federal program under way that aims to stimulate the commercial development of U.S. geothermal resources by private industry and local power authorities. In October 1977, the Energy Research and Development Administration (ERDA) became part of the Department of Energy (DOE) which assumed the national responsibility for developing the required technology to tap the considerable geothermal potential for the U.S., most of which lies in the western and southwestern parts of the country. Both ERDA's and DOE's budgets for geothermal research, development and demonstration have expanded rapidly over the past few years, from roughly $30 million in 1976 to an estimated $130 million in 1979. The DOE works closely with other agencies within the U.S. government, such as the U.S. Geological Survey, the Department of Agriculture, the National Science Foundation, the Environmental Protection Agency and the Department of the Treasury, in its efforts to coordinate the development of geothermal energy. The DOE geothermal efforts are organized along six program elements:

1. Engineering Research and Development focuses on drilling and utilization hardware such as drill bits, heat exchangers and downhole pumps. It has sponsored the design and construction of the world's first direct-contact, binary-cycle heat exchanger, which was successfully tested for 500 hours in a complete 10-kW electricity-producing loop in 1977.

2. The Resource Exploration and Assessment program element develops the instrumentation and techniques needed to find and then evaluate a field's potential and the mathematical models and computer simulations needed to understand and manage geothermal reservoirs effectively. It has developed a systematic, formalized framework for geothermal prospecting and has found evidence of low-to-moderate temperature geothermal resources associated with natural radiogenic heat sources on the U.S. East Coast near large potential markets.

3. Hydrothermal Technology Applications strives to improve systems and systems engineering for the utilization (both electric and nonelectric) of liquid-dominated resources. It is responsible for the operation of the Geothermal Loop Experimental Facility at Niland, California, the Geothermal Component Test Facility at East Mesa, California, and a 40 MWt thermal loop at Raft River,

Idaho. The Geothermal Loop Experimental Facility has successfully tested a flash-to-binary conversion system and a steam-scrubbing system so effective that the steam may be suitable for direct feed to a turbine.

4. Advanced Technology Applications assesses the onshore geopressured resource of the U. S. Gulf Coast and works to demonstrate the feasibility of the Hot Dry Rock concept at the Los Alamos Scientific Laboratory in New Mexico. In 1977 this Laboratory connected a low impedance fracture system between two boreholes and in 1978 operated a 3-MWt energy extraction loop for 2,000 hours.

5. Environmental Control and Institutional Studies, the final program element, investigates the ecological implications and problems of large scale use of geothermal energy and ways of improving federal policies and laws affecting the utilization of geothermal energy in the United States.

The major U.S. national laboratories that support the DOE geothermal program and their specialties are Lawrence Berkeley Laboratory, the center for reservoir assessment, engineering and modeling; the Idaho National Engineering Laboratory, best known for its work on heat exchangers; Los Alamos Scientific Laboratory, home of the Hot Dry Rock Program; Battelle Pacific Northwest Laboratory, focal point for economic studies; Lawrence Livermore Laboratory, developer of the total flow energy conversion system; Brookhaven National Laboratory, center of research on special cements, and Sandia Laboratories, specialists for drilling and logging technology.

APPENDIX 3. SUMMARY OF SELECTED U.S. PROGRAMS RELEVANT TO THE NATO-CCMS GEOTHERMAL PILOT STUDY

INTRODUCTION

The following appendices contain summaries of U.S. geothermal research and development programs relevant to the CCMS Geothermal Pilot Study. Additional information on each of the program areas, GRID and GEOTHERM (Section A), Direct Applications (Section B), Injection (Section C), Joint U.S.-Mexican Program of Resource Investigations at Cerro Prieto (Section D), Well-Head Generator (Section E), and Hot Dry Rock (Section F) may be obtained by writing to the Division of Geothermal Energy, Department of Energy, Washington, D.C. 20545.

A. GRID AND GEOTHERM

GRID

The National Geothermal Information Resource (GRID) of the Lawrence Berkeley Laboratory is sponsored by the U.S. Department of Energy (DOE). Its purpose is to develop a comprehensive compilation of worldwide literature and data designed to assist in the research and development of geothermal energy for both electrical and nonelectrical uses. Included in this compilation are both site-dependent and site-independent energy data related to geothermal utilization, reservoir engineering, physical chemistry, as well as environmental, legal, and economic aspects of geothermal energy. GRID maintains a computerized database which provides the basis for in-depth literature reviews and critical evaluations of data by the technical staff. In addition, computer-produced bibliographic listings and data tabulations are generated from the files for distribution to other data evaluators.

The GRID files currently include the following data categories:

Exploration includes geothermal energy data on geological, geochemical, and geophysical methods, as well as drilling, legal considerations, and land-use factors involved in evaluating and developing sites for electrical power or direct utilization.

Environmental considers effects to the air, land, and water environments from geothermal development, e.g., subsidence, hydrogen sulfide.

Physical Chemistry deals with the basic thermodynamic and transport data at elevated temperatures and pressures of sodium chloride and other salts.

Utilization encompasses the development and production of a geothermal reservoir for both electrical and nonelectrical uses: geothermal fluid transport; space, process, and agricultural heating; corrosion, erosion, and scaling.

Numerical Data contains site-independent and site-dependent tables, including a correlation equation that reproduces NaCl viscosity data.

GEOTHERM

GEOTHERM is the operational computerized file, created by the U.S. Geological Survey, of national and international geothermal resource

information. The file is available to both government agencies and the public.

Objectives:

GEOTHERM creates and maintains a computer data base of geothermal resource information (primarily physical and chemical). The initial goals were format development followed by file creation involving data collection, keypunching, and editing. File maintenance consists of updating data in the file.

Many of these objectives have been met in part or in whole. A file format has been revised and accepted by professionals in geothermal energy and a system for collecting, building, and editing the data is operational. As of November 1, 1977, there were 14,000 records from the United States, Mexico, Republic of China, and New Zealand. The GEOTHERM file is available to private industry and government agencies.

Scope:

GEOTHERM contains site-dependent geothermal information. The format includes three subtopics: Geothermal Field/Area, Chemical Analysis, and Geothermal Well/Drillhole.

Section A: Geothermal Field/Area. This topic includes data on locality, surface description, developments, heat flow, subsurface temperatures and dimensions, porosity, stored heat calculations, general geophysics, geology, and other related information about a geothermal field or area. The coverage is broad and subject to change with time.

Section B: Chemical Analysis. This topic includes chemical analysis data from surface and well samples of a geothermal field. Space is provided for three types of analyses--water, condensate, and residual gas. Data items include sampling conditions, solutes, and isotopes.

Section C: Geothermal Well/Drillhole. This topic contains physical data from geothermal wells and drillholes. Data items include location, temperature, pressure, enthalpy, and well flow.

B. U.S. DIRECT APPLICATIONS PROGRAM

The direct applications program administered by the U.S. Department of Energy's Division of Geothermal Energy is aimed at stimulating commercial development of geothermal resources. A brief description of the program elements is provided below:

1. The low temperature resource assessment program involves cooperative agreements with individual states for assessing their respective low-temperature resources and making this data available to the public.

2. Mitigation of legal and institutional constraints focuses on federal statutes, rules, regulations, procedures, and financing and identifies incentives to overcome obstacles to development.

3. The regional planning effort attempts to determine the overall potential for development and to develop growth scenarios for specific sites.

4. Engineering and economic studies are designed to increase the general knowledge of the potential for direct use of geothermal energy. Near-term commercialization of direct applications would be furthered by a data bank of technical,

environmental, institutional, and economic information. The first group of studies, which were initiated in 1976 and 1977, are nearly complete. These projects included eight studies on process heating, two aquaculture projects, three agricultural applications, three district heating concepts, and one school space heating study. Figures 1 and 2 show examples of direct applications of geothermal energy at Susanville, California.

5. Field demonstrations of several different applications at geographically diverse sites are being funded in fiscal year 1978. These demonstrations, which will be undertaken on a cost-sharing basis by the government and the private sector, will provide actual operating experience and assess the economic feasibility of using geothermal energy directly in place of conventional fuels.

In addition to the award of contracts for particular demonstration projects, the direct applications program also includes general technical

Figure 1. A swimming pool in Susanville, California heated by geothermal energy. (CBB 785-6034)

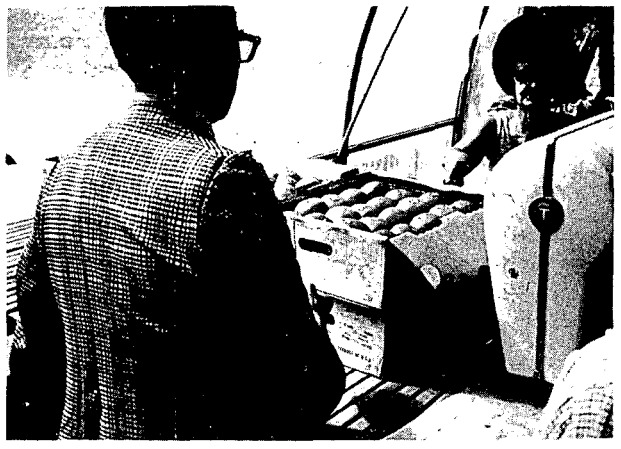

Figure 2. Tomatoes grown in a geothermally heated greenhouse. (BBC 785-6036)

assistance and information for potential users.

STATUS OF CURRENT ENGINEERING AND ECONOMIC STUDIES

Results of the first series of engineering and economic studies were presented at the symposium sponsored by the Geothermal Resources Council and DOE/DGE on Direct Utilization of Geothermal Energy in San Diego, January 31-February 2, 1978 (Reference 1). Some highlights are given below:

1. A study on absorption refrigeration in the food processing industry found that a topping cycle can be used with geothermal resources as a refrigeration cycle and identified the geothermal fluid temperature required for different absorption refrigeration cycle working fluids.

2. A general study on the evaporation and crystallization industry made technical and economic evaluations of direct geothermal applications for three selected industries: preserved fruits and vegetables

(tomato paste processing), sugar and confectionary products (sugar beet refining), and the chemical industry (sodium chloride production). The factors that most affect cost include geothermal resource characteristics (well flow, temperature, and distance of transportation), the duration of the evaporation/crystallization process, and the energy extraction process chosen. The feed-and-bleed extraction process proved superior to simple flashed steam and liquid-liquid heat exchange, primarily because of its lesser fluid flow requirement.

3. A study on geothermal energy industrial complexes has found that in the near future geothermal energy can be used to make forest products in the Northwest, caustic/chlorine products in California, and corn products in Idaho. Other high-potential industries include soda ash production in California and alumina compound/potassium sulfate and soda ash/shale oil/alumina complexes in central Utah.

4. A study assessing the potential for use of geothermal heat in the sugar refining industry found that geothermal energy supply costs are competitive with fossil fuels for conceptual design of a cascade system based on an existing plant in California.

5. A study of geothermal space and water heating at a small California resort community (Mammoth Lakes Village) determined that while initial annual heating costs are higher than with conventional energy costs due to seasonal peak heating needs, an investor-owned geothermal district heating system can provide less costly heating after only six years of operation.

The results of these technical and economic studies will provide a useful base of experience for related projects. Additional studies and a series of field experiments are planned for the next several years. It is hoped that this initial work will provide the needed impetus to establish a viable nonelectric industry.

C. U.S. INJECTION PROGRAM

Injection of spent geothermal fluids has been recognized as the best method of disposal for two major reasons: (1) environmental compatibility, and (2) reservoir enhancement. Disposal of geothermal fluids of varying chemical content by surface techniques can create many environmental problems. However, waste fluids from hydrothermal systems can be injected back into the same system from which they are withdrawn or into one similar to it. Injection will reduce or even possibly eliminate subsidence that may occur in a producing geothermal field. Injection may also help to extend the life of a reservoir through the emplacement of fluid back into the geothermal system.

However, there are certain problems associated with injection of geothermal fluids. In several documented cases, mineral deposits have plugged injection wells. There is also evidence that injection may cause low magnitude seismic activity in the injection area or the contamination of aquifers.

Various investigations are being carried out to answer some of the questions relating to injection. The programs can be grouped into

three major categories: (1) Reservoir Engineering, (2) Brine Chemistry, and (3) Environmental Effects.

Injection investigations in the United States related to Reservoir Engineering are primarily concerned with predicting the effects of injecting fluids back into geothermal systems. This is a complex problem because it involves the flow of fluid in a porous fractured medium with thermodynamic and rock/fluid interactions. It is also difficult to evaluate the effects of injection on the distribution of temperature and pressure within the geothermal system. While the injected fluid may provide recharge and increase production, it may conversely have the detrimental effect of lowering reservoir temperature. Many of the investigations being conducted on various geothermal reservoirs are designed to investigate these possibilities and develop mathematical models which predict the effects of injection, given different development plans. One example of such an investigation is at the East Mesa field, shown in Figure 3.

At present, investigations are being carried out at several geothermal sites. The Lawrence Berkeley Laboratory is studying the injection effects at Larderello, Italy; Cerro Prieto, Mexico; and Imperial Valley, California. These investigations are designed to provide information on both vapor-dominated systems and high-temperature, liquid-dominated systems. The Lawrence Livermore Laboratory has been conducting investigations for several years on the injectability of high salinity brines at Niland, California. The Idaho National Engineering Laboratory has begun a program to investigate the effects of injecting medium temperature fluids at Raft River, Idaho. The Geysers area of California is another geothermal field where the effects of injection have been studied. Extensive information relating to injection of fluids into a steam-dominated system has been gathered at this site.

The chemistry of geothermal fluids plays a critical role in the success of injection. The problems of scale deposition in injection wells has been well documented. A major effort is being undertaken by the Division of Geothermal Energy (DGE) to solve the problems of scale build-up both in the wells and/or in the formation. These include projects investigating scale formation and suppression, waste utilization, chemical control and instrumentation development for detection and monitoring of fluid chemistry and scale deposition. The emphasis of the program is directed at identification of energy systems, their geochemical engineering operations, management of the chemical process fluid and appropriate waste materials control equipment. Another program is addressing the problem of injection stimulation and is designed to develop geothermal fluid reinjection techniques that will minimize clogging of injection wells. All of these investigations are being conducted through various national laboratories and outside contracts. The national laboratories involved include Lawrence Berkeley Laboratory, Los Alamos Scientific Laboratory, and Battelle Pacific Northwest Laboratory.

Another program within DGE involves the environmental effects of geothermal fluid disposal through injection. This program will address the engineering specifications, equipment operating procedures and potential hazards of waste disposal through injection. Specific methods which will be examined include: (1) injection at the producing horizon, (2) injection in a non-producing horizon, (3) treatment and injection, and (4) injection to enhance additional fluid production.

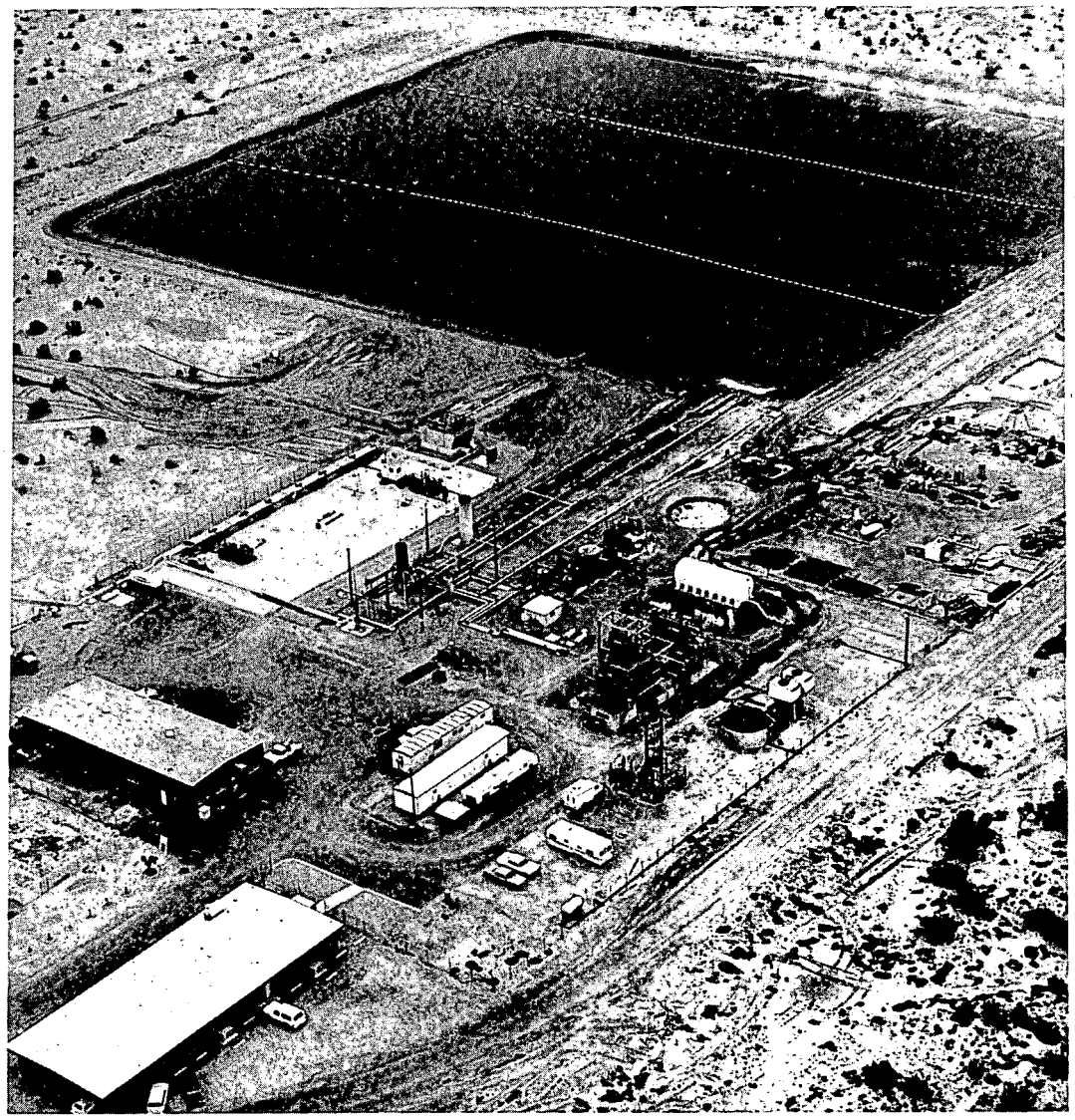

Figure 3. An aerial view of the East Mesa Geothermal Test Facility (photo by the Bureau of Reclamation).
(XBB 785-6274)

Investigations are under way to determine the environmental effects of injection under each of the above categories. The U.S. Geological Survey, through a cooperative project with DGE, is studying the possibility of induced seismicity as related to both production and injection at The Geysers geothermal area. Planned studies will include the investigation of subsidence control through injection of geothermal fluids. These projects are included in an overall subsidence program being managed by Lawrence Berkeley Laboratory.

D. JOINT U.S.-MEXICAN PROGRAM OF RESOURCE INVESTIGATIONS AT CERRO PRIETO

INTRODUCTION

Cerro Prieto (see Figure 4) was among the first liquid-dominated geothermal systems in the world to be developed,

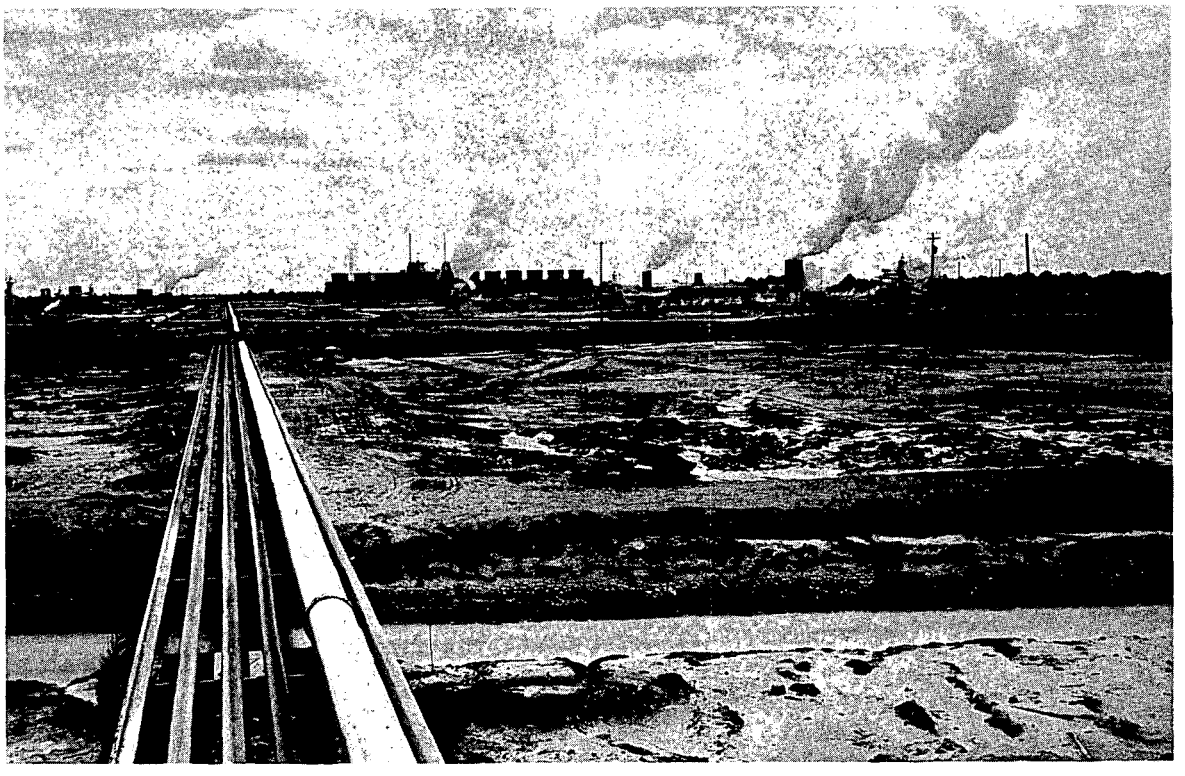

Figure 4. Steam pipes from production wells to the 75-MWe geothermal power plant at Cerro Prieto, Mexico. (CBB 771-9594)

and an emerging reservoir history is available for analyzing the behavior of this system. Under the U.S.-Mexican Bilateral Agreement, many of the techniques used in the evaluation of geothermal systems will be refined and improved through their application at Cerro Prieto. Better reservoir engineering techniques can contribute to the evaluation of geothermal prospects being developed throughout the world. It is hoped that the cooperative effort by the United States and Mexico will accelerate geothermal development in both these countries and encourage technical collaboration among other countries in the area of geothermal energy.

OBJECTIVES

The objectives of cooperative investigations at Cerro Prieto are (1) to develop a thorough understanding of the nature and magnitude of the energy resource, (2) to investigate how the geothermal system can best be developed consistent with the long-range needs of the Comisión Federal de Electricidad, and (3) to determine the surface and subsurface environmental impact of such development. By working together, Mexican and American geothermal teams will be able to investigate and develop methods of understanding and exploiting geothermal resources at Cerro Prieto that can produce benefits on both sides of the border. The location of geothermal wells in the Cerro Prieto field is illustrated in Figure 5. An understanding of the subsurface system at Cerro Prieto and the manner in which the reservoir can be analyzed and exploited is directly applicable to the several geothermal anomalies already identified in the Imperial Valley. The proposed program will

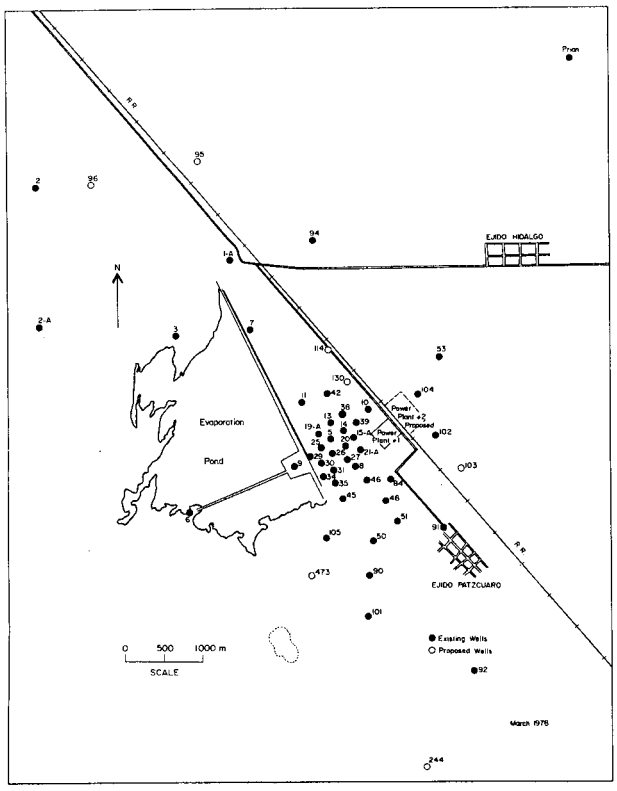

Figure 5. Location of geothermal wells in the Cerro Prieto field, Mexico. (XBL 783-7889)

involve the use of new instrumentation for gathering reservoir data, application of precise methods of measuring land movements, the use of mathematical models in predicting the future behavior of the geothermal systems, and development of a strategy for injection of waste brine.

THE PROGRAM

The Mexican Comisión Federal de Electricidad (CFE) and the United States Department of Energy (DOE) will act as the lead agencies for implementing the tasks specified in the bilateral agreement. Other agencies involved in the project through CFE or DOE include Dirección General de Estudios Del Territorio Nacional (DETENAL) and Centro de Investigación Científica y Educación Superior de Ensenada (CICESE) from Mexico, and the United States Geological Survey, the Lawrence Berkeley Laboratory, and the University of California at Riverside from the United States.

Seven tasks are specified in the Mexican-United States bilateral agreement for cooperative research at Cerro Prieto. They are:

Task 1--Geology and Hydrology. Collect, analyze and evaluate the available geological, geochemical, and reservoir information for definition of the geothermal system's geologic structure.

Task 2--Geophysics. Define the limits and gross structure of the field in order to better understand the functioning of the geothermal system and to monitor reservoir behavior during production through surface geophysical techniques.

Task 3--Reservoir Engineering. Define the size, geometry, physical characteristics, fluid capacity, recharge capability, production ability and energy longevity of the reservoir.

Task 4--Injection. Verify analytical models of reservoir behavior under exploitation and reinjection and analyze hydrodynamics, thermodynamics and subsidence effects.

Task 5--Isotopic Analysis. Determine the origin of the geothermal fluids and the possible recharge sources and rates.

Task 6--Subsidence. Establish and maintain a joint crustal-strain monitoring program in the Mexicali Valley through vertical and horizontal measurements.

Task 7--Cerro Prieto Conferences. Ensure accurate interpretation of research information and encourage its application at other geothermal development sites.

The Bilateral Agreement was signed in July 1977. The first meeting, held at Lawrence Berkeley Laboratory in September, was for the purpose of exchanging information on what is known about the Cerro Prieto geothermal system and coordinating future activities with respect to the individual tasks. Other activities relating to the Agreement were initiated immediately after signing of the agreement and are being carried out at the present time. These include Task 5, isotopic analysis, being carried out by the U.S. Geological Survey, and Task 1, collection of geological and hydrological information (References 2-4). Initial coordination through planning meetings and/or on-site visits have been accomplished for the remainder of the tasks. A second general meeting, sponsored by the CFE, was held in Baja California in November to explain the program to other Mexican agencies and scientists. A major portion of the work in Cerro Prieto will be conducted during fiscal years 1978 and 1979.

Two conferences are tentatively scheduled in fiscal year 1978 to exchange information on the progress of cooperative activities.

Thus far, the Bilateral Agreement has provided a very effective link between the U.S. and Mexican scientists in their cooperative investigations at Cerro Prieto. The technical program is expected to be completed by 1980-81, and the results will contribute substantially to the refinement of models for the Salton Trough, definition of the geothermal potential for both Cerro Prieto and Imperial Valley, and methods of monitoring and predicting reservoir behavior. In addition, a regional network of stations for first-order leveling and trilateration will be established, tying subsidence measuring efforts already being carried out by the Mexicans at Cerro Prieto into the American work being carried out in the Imperial Valley.

E. U.S. WELLHEAD GENERATOR PROGRAM

The U.S. Department of Energy's Division of Geothermal Energy has three current activities related to electric power production from wellhead generators:

1. a market survey,
2. a demonstration of a 1.2-MWe helical screw expander, and
3. a planned demonstration of a 3-MW flash-steam turbine generator.

The first two of these will be completed during the present fiscal year; the flash steam system will be tested during fiscal years 1979 and 1980.

The market survey is based upon a technical and economic analysis of the state-of-the-art generic wellhead conversion system coupled with interviews of representatives of various firms characteristic of the industry (utilities, architect-engineers, equipment manufacturers, and resource developers). A synthesis of the information from the interviews and studies will be developed and an estimate of the market potential will be made.

A four-month demonstration test of a 1.2-MWe helical screw expander began at Roosevelt Hot Springs, Utah, beginning in April 1978 (see Figure 6). The skid-mounted unit,

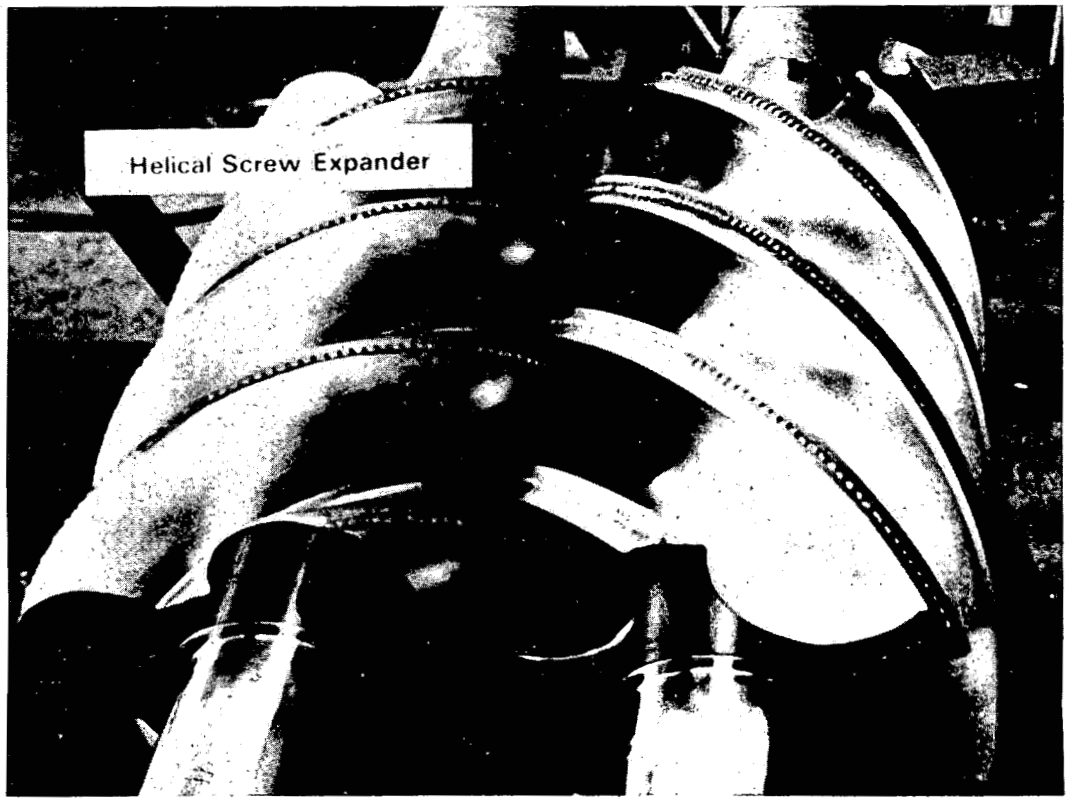

Figure 6. Prototype of the helical screw expander now being tested at Roosevelt Springs, Utah.
(XBB 785-6280)

which has passed acceptance tests, will be operated in a non-condensing mode over a wide range of the performance map to demonstrate both efficiency and reliability. Upon successful conclusion of the demonstration tests, the machine is expected to be suitable for commercial use.

The third element of the program involves the purchase, installation and operation of a flash steam turbine providing approximately 3 MWe to a utility grid. The test will be conducted on a well previously drilled by the federal government for geothermal resource assessment purposes. It is expected that the system will provide base load power that is economic, reliable and environmentally acceptable. A condensing turbine and appropriate H_2S abatement system will ensure minimum environmental impact.

The sum of these three program elements is expected to accelerate geothermal development by establishing the feasibility and desirability of unattended operation of small power plants, which produce an early return on drilling investment, provide valuable reservoir engineering data, demonstrate equipment compatibility with geothermal fluids and demonstrate the ability to cope with environmental regulations. Subsequent development of promising geothermal fields may then follow either with a central station power plant strategy or an incremental wellhead development strategy with minimum risk to the investor.

F. U.S. HOT DRY ROCK PROGRAM

The hot dry rock resource base is defined by the U.S. Department of Energy (DOE) as that portion of the unmelted crustal rock that underlies the United States at depths less than 10 kilometers and at temperatures high enough to be useful for electric generation or direct use as heat but that does not spontaneously produce hot water or steam at a rate adequate for economic extraction.

The resource base is extremely large, and its magnitude dictates a program to determine if it can be economically exploited in competition with other energy sources such as coal and solar. Exploitable hot dry rock reservoirs occur in two principal geological environments: areas of recent volcanism and regional conductive environments. In the crystallized parts and hot margins of igneous systems, it is estimated there exists a heat content of about 190,000 quads (1 quad = 10^{15} Btu) above a reference temperature of 300°C at variable depth but generally less than 10 km. In regional conductive environments, the geothermal gradients are generally lower than in volcanic regions, and depths to usefully hot rock are correspondingly lower. Here again, at depths less than 10 km but a temperatures above 15°C, the heat content is estimated to be 31,750,000 quads.

The percentage of the resource base that might ultimately be economically recoverable in the United States is highly speculative, but if it were as high as two percent then the energy recoverable from hot dry rock would be about 260,000 quads at temperatures above 150°C.

In addition to the size of the resource base, another major incentive for hot dry rock is the potential flexibility of selecting sites near major load centers. This would be particularly important in the eastern United States, which is remote from good hydrothermal sites and where recent DOE-sponsored studies indicate hot dry rock resources in commercially exploitable quantities may exist.

The hot dry program of the U.S. Department of Energy has two main goals. One is to establish the technical feasibility of the hydraulically fractured hot dry rock system for impermeable rock by 1980. The other is to confirm the technical feasibility and to obtain economic data for hot dry rock energy extraction systems in the commercial size range by 1985. In 1976, 1977 and 1978, the program was funded at a level of around $5 million per year, but the President's 1979 budget submission to the U.S. Congress asked for an increase to $12 million.

The U.S. hot dry rock program began in 1972 with the drilling of a slim geothermal test hole to a depth of 785 m on the edge of the Valles Caldera, a site west of the Los Alamos Scientific Laboratory (LASL) at Los Alamos, New Mexico. Here over the next five years, the Laboratory proceeded to develop the technologies required for the hot dry rock energy system, such as fracture mapping, borehole locating and ranging equipment, open hole packers, directional drilling procedures and devices, and logging instruments, all for operation at high temperatures. The specific concept pursued at LASL requires the drilling of a deep borehole in impermeable rock to attain high temperatures, creation of a large hydraulic fracture, and the drilling of a second borehole to intersect the fracture. Water is pumped down one hole and hot water or steam extracted from the other. Such a system was successfully

achieved in the summer of 1977 at the Los Alamos site, at an approximate depth of 3 km and with a maximum rock temperature of nearly 200°C (see Figure 7).

Based on this success, heat exchangers, pumps and necessary piping were added to form a closed loop system and in the fall of 1977 a 100-hour initial test at a nominal 3 MWt was conducted. In order to determine the mechanical, physical and chemical properties of the reservoir and the heat exchange system, the Laboratory began in January 1978 to operate the system continuously in a test run for a period of about 2100 hours. If this test is successful, there will be new drilling for a 100-MWt experimental system which would provide unique and useful information on the design and construction of a small-scale electric generating plant.

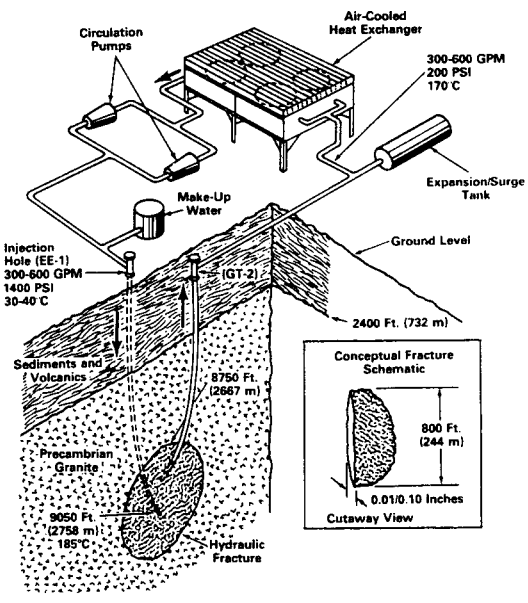

Figure 7. Schematic of the LASL hot dry rock geothermal concept at the Fenton Hill extraction loop. (XBL 785-8748)

In part because of these accomplishments, DOE has initiated in 1978 activities toward a national hot dry rock program. This expansion of the program will include resource assessment and characterization on a national scale through reconnaissance and exploration. Additional heat extraction tests will be performed to establish technical and economic feasibility in other geological settings. As appropriate, a number of pilot and demonstration plants for electric power generation or direct heat applications will be developed.

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This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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