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**GEOCHEMICAL ENGINEERING PROBLEM
IDENTIFICATION AND PROGRAM DESCRIPTION**

Final Report

By
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May 1981

Work Performed Under Contract No. AC07-80ID12183

Engineering and Economics Research, Inc.
Falls Church, Virginia

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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FINAL REPORT

GEOCHEMICAL ENGINEERING
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AND PROGRAM DESCRIPTION

MAY 1981

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Prepared For

DIVISION OF GEOTHERMAL ENERGY
U.S. DEPARTMENT OF ENERGY

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	iv
LIST OF TABLES	v
ACKNOWLEDGMENT	vi
I. INTRODUCTION.....	1
A. Background	1
B. Purpose of Document	4
II. PROGRAM GOAL AND OBJECTIVES.....	5
A. Goal	5
B. Strategy	5
C. Scope and Definition of Problems	7
D. Rationale	17
E. Objectives	27
III. PROGRAM ORGANIZATION.....	33
A. Program Structure and Objectives of Program Elements	33
B. Program Priorities and Funding	36
C. Program Management	43
IV. PROGRAM STATUS.....	47
A. Fluid Characterization	47
B. Geochemical Monitoring and Control	55
C. Fluid Handling	60
D. Technology Transfer	68
E. Accomplishments	70
REFERENCES	72

LIST OF FIGURES

<u>Figure Number</u>		<u>Page</u>
1	Percent Frequency of Identified Hydrothermal Resources by Temperature	2
2	General Geochemistry Problems in a Steam or Flash Electric Plant	11
3	General Geochemistry Problems in a Binary Electric Plant	12
4	General Geochemistry Problems in a Typical Direct-Heat Plant	13
5	Estimated Program Element Funding, 1978-1988	44
6	Funding Requirements for Identified Industry and Government Programs, 1978-1988	45
7	Major Fluid Characterization Milestones	54
8	Major Geochemical Monitoring and Control Milestones	58
9	Major Fluid Handling Milestones	66
10	Major Technology Transfer Milestones	69

LIST OF TABLES

<u>Table Number</u>		<u>Page</u>
1	Chemical Species Found in U.S. Geothermal Fluids and Their Concentrations (ppm)	8
2	Relationship of Geochemical Engineering Concerns to Generic R&D Needs	9
3	General Geochemistry Problems Experienced in Early Exploratory Drilling in U.S.	18
4	Some Geochemistry-Related Problems Experienced or Expected in Site-Specific Developments	19
5	Illustrative Cost and GEM Programs Savings Data for Geothermal Electric Plants	25
6	Percentage Plant and Component Cost Savings Due to Geochemical Engineering and Materials Program	26
7	Benefit/Cost Ratios for Some Geochemical Engineering Program R&D Areas	28
8	Some Savings Attainable Through the Geo-chemical Engineering Program	29
9	Summary of Benefits of Geochemical Engineering R&D	30
10	Geochemical Engineering Program Elements and Subelements	34
11	Geochemical Engineering Program Elements Priorities	38
12	Fluid Characterization: Element Priorities and Funding	39
13	Geochemical Monitoring and Control: Element Priorities and Funding	40
14	Fluid Handling: Element Priorities and Funding	41
15	Technology Transfer: Element Priorities and Funding	42
16	Matrix of Completed and Active Projects and Addressed Subelements	48

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I. INTRODUCTION

A. Background

Geothermal energy can be found in three accessible forms: hydrothermal, geopressured, and hot dry rock resources. Hydrothermal resources represent the most exploitable form of geothermal energy in the immediate and near-term in the U.S. These resources may be either vapor-dominated or liquid-dominated subsurface reservoirs of heated and pressurized fluids and can be tapped to produce fluids at temperatures as high as 680°F.

High-temperature hydrothermal resource fluids ($\geq 400^{\circ}\text{F}$) are generally either vapor-dominated or can be easily flashed to steam. These resources can be economically exploited for electric power generation using existing technology. Geothermal steam or flash-steam power plants have been producing electricity for over 75 years in other parts of the world and for over 20 years in the United States.

Current interest, however, is directed at the much more abundant "moderate"-temperature resources (300-400°F) which are currently uneconomic to exploit due to the relatively low efficiencies and/or high capital/O&M costs of state-of-the-art technologies.

The United States Geological Survey (USGS) estimated in 1978 that discovered hydrothermal resources exceeding 150°C (302°F) are equivalent to approximately 23,300 MWe for 30 years.⁽¹⁾ The liquid-dominated resource base represents an estimated 21,800 MWe potential, of which about 33% is associated with fluids in the 300-400°F range. Figure 1 is a

⁽¹⁾Reference 1.

FIGURE 1
PERCENT FREQUENCY OF IDENTIFIED
HYDROTHERMAL RESOURCES BY TEMPERATURE

SOURCE: Reference 1.

frequency/temperature histogram for identified U.S. hydrothermal resources. This illustrates the relative magnitude of the $\geq 300^{\circ}\text{F}$ (about $\geq 150^{\circ}\text{C}$) resource base. USGS anticipates the discovery of additional resources above about 300°F over the next 20 years that could expand generating capacity to as much as 150,000 MWe for 30 years. It is expected that moderate-temperature resources will comprise an increasingly larger proportion of the known hydrothermal resource base as more resources are discovered. This is due to the fact that high-temperature reservoirs tend to be the more easily discoverable. If technology can be developed to economically exploit this moderate (or even lower) temperature resource base, the current national dependence on conventional fuels can be noticeably reduced.

The first electricity generated from hydrothermal resources in the U.S. came on-line in 1960 (20 MWe) at the Geysers vapor-dominated resource in California. Generating capacity at this steam-field anomaly has increased since that time to a current level of about 900 MWe, establishing the site as the world's largest geothermal electric power complex. Additional electric facilities are located at liquid-dominated sites at East Mesa, California (10 MWe), Brawley, California (10 MWe) and Raft River, Idaho (5 MWe); not all of these plants, however, have achieved full, sustained operation yet. Developers and utilities have announced plans to construct another 38 hydrothermal electric power plants in the U.S. by 1989, most in California's Imperial Valley, which will add 2,135 MWe to existing capacity.

A major thrust of DOE's geothermal program is to carry out long-range/high-payoff R&D on technical problems associated with the extraction, handling, and disposal of geothermal fluids. The combined Geochemical Engineering and Materials (GEM) Programs within the Division of Geothermal Energy (DGE) address these problems by pursuing two separate but interrelated areas of research: (1) development of cost-effective materials durable enough for use in a wide range of geothermal environments, and (2) improvement of geochemical fluid management techniques. Although these two aspects have much in common with regard to specific problem areas, technical program objectives, R&D requirements, and resulting cost reductions, they can be differentiated according to their materials or geochemical engineering orientation. Separation of geochemical engineering and materials R&D into two programs is necessary for precise problem identification and the development of appropriate problem-solving techniques.

B. Purpose of Document

This document presents the strategy and status of the Geochemical Engineering Program. The purpose of this document is to:

- (1) describe the magnitude and scope of geochemical-related problems constraining geothermal industry productivity;
- (2) define the goals and objectives of the DGE Geochemical Engineering Program;
- (3) describe the rationale and strategy of the program;
- (4) delineate the structure, priorities, funding, and management of specific elements within the program; and
- (5) present the status of the overall program.

II. PROGRAM GOAL AND OBJECTIVES

A. Goal

Within the overall framework of the geochemical engineering and materials effort, the specific goal of the Geochemical Engineering Program is to:

- Carry out high-risk/high-return research projects that can lead to private sector development of cost-effective technology and procedures for maintaining, enhancing, and efficiently exploiting the desirable properties of geothermal fluids while providing adequate control of fluids and solids throughout the utilization process.

B. Strategy

Achievement of the program goal requires the effective management of a wide range of research problems and technology transfer mechanisms. Therefore, DGE's strategy in the Geochemical Engineering Program is, in cooperation with industry, to:

- (1) identify and define specific technical chemistry-related constraints to geothermal energy utilization;
- (2) prioritize the constraints according to the benefits expected to accrue from their successful removal;
- (3) identify areas where selective federal support and coordination activities related to geochemical engineering generically support the private sector and have potential to increase national productivity; and
- (4) identify and implement optimum mechanisms for information dissemination and technology transfer within the geothermal community.

The technical problems considered for federally-supported R&D under the Geochemical Engineering Program are identified through ongoing assessments of world-wide experience with geothermal and closely-related operations and of the special requirements of U.S. geothermal resource utilization. This interactive process involving government, industry, and academic institutions provides the continuous feedback necessary for a sound technical program and creates an awareness of geochemical engineering, manpower, and research needs and opportunities.

Within the context of the guiding strategy, DGE's approach is to fund long-term applied R&D designed to have significant impacts on industry viability and productivity through improvements in fluid management techniques and costs. Implicit in DGE's technology transfer efforts with industry is the evaluation of existing non-geothermal technologies, methods, and concepts for application in geothermal resource development. Only where experience in similar industries is not transferable and where private sector initiatives are not planning to address long-range geothermal needs does the federal government consider industrial support. A mature geothermal industry comparable to the established oil, gas, and other resource exploitation industries does not exist. Resource exploration and development companies, utilities, small-scale energy producers/consumers, supply/service organizations, professional societies, and other interested parties are presently organizing task groups that help serve as focal points for industry/government interactions. Since support research is not being carried out by the private sector due to the

relatively small market for geothermal systems, DGE's strategy is to sponsor the long-term R&D that the private sector has been unable to undertake.

C. Scope and Definition of Problems

Geothermal fluids in the U.S. contain chemical species of varying types and concentrations (see Table 1) which, in addition to or in combination with high fluid temperatures, can be troublesome in the fluid extraction, energy conversion, and waste disposal processes of a geothermal power plant. It is unfortunate in this respect that the subsurface environment that provides this useful thermal energy source also imparts aggressive chemical properties to the heat-carrying fluids. The chemically-complex and site-specific fluid compositions, high temperatures encountered, and large fluid volumes usually required present unique utilization problems for which there is little adequate technology or operating experience directly transferable from other industries.

The primary chemistry-related problems arising in the utilization of geothermal fluids are corrosion of materials, precipitation, scaling, undesirable emissions and wastes, and process engineering requirements for effective fluid handling. Table 2 identifies the range of geothermal engineering problems that are constraining the development of adequate geothermal technology. The table also shows that this unique mix of factors can be reduced to a limited number of "generic" problem areas that represent high-impact focal points for R&D efforts.

TABLE 1
CHEMICAL SPECIES FOUND IN U.S.
GEOTHERMAL FLUIDS AND THEIR
CONCENTRATIONS (ppm)

GEOTHERMAL RESOURCE FLUID CHARACTERISTIC	BOISE, ID	BEAUNE, NV	LONG VALLEY, CA	RAFT RIVER, ID	EAST MESA, CA	COSO, CA	PUNA, HI	ROOSEVELT, UT	BACA, NH	WEBER, CA	EAST MESA, CA	BRANLEY, CA	SALTON SEA, CA	SEA WATER
Temperature (°C)	80	242	238	146	180	238	280	240	294	190	204	147	200-340	
pH	9.0	9.3	8.5	7.4	—	—	1.4	8.5	6.8	NR	5.5	6.9	4-7	8.2
Total Dissolved Solids	290	855	1100	1598	1804	5610	6000	6442	7034	13168	26300	52625	151237-319000	
Cl ⁻	10	50	227	784	535	2480	2980	3400	3400	7420	15850	31000	20500-280000	19000
Na	1.7	214	308	442	680	1590	1740	2000	2000	5500	8100	13900	45500-74000	10500
K	1.6	9	32	37	30	126	158	410	463	220	1050	2400	6500-25000	380
Ca	1.7	—	4	57	2.5	93	71	10.1	27	1062	1360	2560	2200-40000	400
Li	0.05	—	0.3	1.3	0.92	10.3	—	19	—	4	40	—	29-300	0.17
Sr	—	—	—	1.4	0.80	3.7	1.2	—	—	37	320	—	85-750	8
Ba	<0.2	—	—	<0.4	<0.2	—	—	—	—	8	14	—	85-570	0.03
Ce	—	—	—	—	—	<0.01	—	—	—	—	—	—	15-20	0.0005
Br ⁻	—	—	—	<1.5	—	—	—	—	—	—	—	—	25-148	85
F ⁻	2-14	6	20	7.3	—	3.8	—	5	—	1.7	0.99	—	2.4-18	1.3
SO ₄ ²⁻	2.3	89	96	54	10-50	257	317	54	70	100	42.8	885	0-56	885
Hg	0.05	—	—	1.8	0.06	2.7	62.5	0.24	—	5.6	17.2	1300	0-100 113-3000	1350
Rb	—	—	—	—	—	0.112	—	—	—	—	—	—	50-169	0.12
Fe	0.13	—	5	0.8	0.2	—	—	—	—	15	8.8	0.4	60-3000	0.01
Mn	0.01	—	—	0.6	<0.06	—	—	—	—	0.9	0.95	—	6.4-2.500	0.002
Pb	<0.005	—	—	—	<0.5	—	—	—	—	1.6	—	—	<4-155	0.00003
Cu	0.08	—	—	—	—	—	—	—	—	0.5	—	—	0-16.5	0.003
Ag	—	—	—	—	<0.06	—	—	—	—	—	—	—	0-1.4	0.00004
Ni	<0.02	—	—	—	0.0008	—	0.0005-0.0444	—	—	—	—	—	0.006-0.2	0.00004
As	<0.05	—	0.2	—	—	—	—	—	—	—	0.26	—	0.16-15	0.003
B	0.14	1	11	0.3	1.5	0.56	—	29	—	4.1	9.75	—	100-745	4.6
Zn	—	—	—	—	0.5	—	—	—	—	0.3	0.07	—	283-740	0.01
SiO ₂	100-1000													3
Bi	Trace	0	—	0.9	—	—	—	—	—	—	0.1	—	<0.6-6.5	0.002
Al	<0.005	0.2	2	—	<0.3	—	—	—	—	15	0.04	—	<0.1-450	0.01
Cd, Cr, Co Mo, Se, I	MINOR AMOUNTS													Can be Significant
H ₂ S	<0.001	6	14	14	NR	—	200	NR	1.5-6	2	3	—	10-30	
CO ₂	0.2	209	180	60	550	280	NR	—	128	180	202	1582	1000	
NH ₃	—	3	0.1	2	0.1-1	—	NR	NR	—	13	41	165	300	

Source: Reference 2.

TABLE 2

RELATIONSHIP OF GEOCHEMICAL ENGINEERING CONCERNS TO GENERIC R&D NEEDS

<div>ACTUAL AND POTENTIAL GEOCHEMICAL ENGINEERING CONCERNS</div> <div>R,D&D NEEDS</div>	EVALUATION OF NATIONAL RESOURCE BASE	SITE-SPECIFIC RESOURCE ASSESSMENT	SITE-SPECIFIC SYSTEM AND COMPONENT DESIGN	MATERIALS SELECTION/ DEVELOPMENT	MATERIALS DAMAGE	WELL DRILLING AND OPERATION	DOWNHOLE MONITORING	IN-LINE PROCESS MONITORING	SCALING AND FOULING	MAINTENANCE OF FLOW RATE	UNPLANNED VARIATIONS IN FLUID CHARACTERISTICS	MAINTENANCE OF POWER OUTPUT	MAINTENANCE OF HEAT EXCHANGE EFFICIENCY	BRINE DISPOSAL	NON-BRINE WASTES DISPOSAL	POLLUTION	WELL LIFE	DOWNTIME	SAFETY	LACK OF KNOWLEDGE	INSUFFICIENT MARKET INCENTIVES	LACK OF DEMONSTRATED TECHNOLOGY	LACK OF OPERATING EXPERIENCE	INADEQUATE INDUSTRY INFRASTRUCTURE
Sampling and Analysis Methods Development	X	X	X	X	X		X	X	X	X	X				X					X	X	X	X	X
Fluid Inventory	X	X		X									X	X	X					X	X			
Sensor Development					X		X	X	X	X	X	X			X		X			X	X	X	X	X
Instrumentation Development	X		X			X				X		X	X		X		X		X		X	X	X	X
Scale Control			X	X	X	X			X	X		X	X	X			X	X		X	X	X	X	X
Component and System Design Operation			X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Brine Disposal		X	X	X	X	X			X	X				X		X	X	X		X		X	X	
Non-brine Wastes Disposal			X	X	X										X	X			X	X		X	X	
Waste Treatment and Byproduct Recovery			X	X	X								X	X	X				X	X	X	X	X	
Cooling Systems Design		X	X	X	X				X	X		X	X	X		X				X	X	X		
Modeling of Fluid Process Chemistry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Plant Case Studies		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Information and Technology Transfer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Since corrosion is a materials-fluid interaction and since the main approach to addressing corrosion problems is appropriate materials selection and development, this subject is not dealt with in depth in this report; it will be discussed in a parallel document produced for DGE's Geothermal Materials Program. Corrosion, in its many forms, is primarily a damage-oriented phenomenon, producing physical degradation of materials and consequent failure of components. The other aspects of the geochemistry problem, on the other hand, can result in an essentially different range of problems in geothermal utilization systems, such as reduced production and through-plant flow rates, need for well and plant cleanout services, waste treatment and disposal problems, environmental contamination, inappropriate process design engineering, and so on.

Figures 2 through 4 identify general geochemistry-related problems in steam/flash electric, binary electric, and direct-heat facilities; the problems shown tend to be those that are associated with particular locations in the system and are in addition to system-wide concerns of fluid chemistry modeling, safe and efficient fluid handling, and design optimization. The following discussion outlines the types and scope of chemistry-related problems faced by developers of geothermal resources.

Solids precipitation and/or scaling has been, or will be, a significant problem at a number of important development sites. There are different chemical types and physical forms of scale deposits which can occur in flowing geothermal brines. The occurrence and degree of precipitation and scaling depend on a number of factors, including brine composition and pH, temperature, pressure, velocity and hydrodynamic effects, residence time, surface effects,

FIGURE 2
GENERAL GEOCHEMISTRY PROBLEMS
IN A STEAM OR FLASH ELECTRIC PLANT

FIGURE 3
GENERAL GEOCHEMISTRY PROBLEMS
IN A BINARY ELECTRIC PLANT

FIGURE 4

GENERAL GEOCHEMISTRY PROBLEMS
IN A TYPICAL DIRECT-HEAT PLANT

fluid phase, and geometry of plant components. The natural variability of geothermal fluids can influence many of these factors and hence the tendency for solids to form, but the utilization system itself can exacerbate precipitation and scaling through process-induced changes in fluid characteristics. Precipitation and/or scaling can restrict and eventually plug production and injection well flows, significantly decrease the interior diameter of piping, coat surfaces of process equipment (a serious problem in heat exchangers), jam valves, cause in-line sensor devices to become inoperative, and lead to increased erosion and wear throughout the system. Problem scaling can, in fact, be caused by constituents of the fluid which are present in only very small amounts.

In addition to precipitation and scaling, which are readily apparent manifestations of geochemical problems, there are other, perhaps less obvious, aspects. One is the need to characterize the geothermal fluids at each resource, and even each well, in order to accurately predict the behavior of the fluids during extraction, energy conversion, and disposal. Fluid characterization is essential for identifying the preferred utilization system at a particular site, anticipating and addressing site- and system-specific problems, and aiding in the evaluation of the national geothermal resource base. Suitable and accurate techniques must be developed for sampling and analyzing the fluids at the resource exploration stage for proper resource assessment and process design and at the plant operation stage for efficient process control. Another problem in plant operation is the lack of sensors and instrumentation that can function reliably in high-temperature and chemically-complex geothermal environments, and, therefore, ensure adequate fluid monitoring and control in surface facilities and downhole.

The efficient, safe, and environmentally-acceptable design and operation of a geothermal facility require not only input from fluid characterization efforts, but also from modeling studies intended to gain a thorough and predictive understanding of fluid kinetics and thermodynamics. The current state of knowledge with regard to geothermal fluid process chemistry is deficient in a number of important areas, especially fluid/formation interactions in production and injection wells. The aspects of fluid composition and interactions that create problems for maximized fluid production and energy conversion efficiency also affect the environmental compatibility of the various air emissions and liquid and solid wastes that can be generated. Waste treatments may be borrowed or adapted from industries with similar wastewater treatment requirements, but new techniques may have to be developed. Since there is a limited geothermal market for any novel treatment techniques, they must also be attractive options for non-geothermal applications.

Since it is only the heat content or kinetic energy of geothermal fluids that represents the "fuel" source, large quantities of "unconsumed" geothermal brine must be disposed of. The most frequently used method of brine disposal for electricity-generating plants will be subsurface injection back into or near the producing reservoir. An array of technical and economic problems is presented by this costly disposal technique, including proper siting and drilling of the injection well, optimizing and maintaining injection rates, protecting higher-quality groundwater supplies, and anticipating the interactions of the injected fluid and receiving formation. Non-injection disposal options, namely onto the land or into surface water features, tend not to be as technically complex, but rather may require fairly expensive water treatments to bring the wastewater quality up to acceptable levels.

Other wastes from the main energy-producing or ancillary processes, e.g., wastes from well drilling, air pollution abatement, and wastewater treatment, also require proper handling within the economic constraints of the overall development. It is notable that solid wastes from geothermal power plants may be officially classified as hazardous wastes, which imposes special regulatory controls on their disposal.

Many geothermal resources are located in either water-scarce regions or areas where the local water supplies that are present are already primarily committed to higher-priority drinking water, irrigation, industrial, or other uses. Therefore, it is becoming increasingly necessary to consider the use of geothermal fluids to satisfy power plant cooling water needs. The geochemical engineering problems present in the main energy-conversion system can be compounded in a cooling system utilizing cooled and aerated geothermal brine. The primary concerns are increased corrosion and scaling, in addition to which cooling tower drift may pose pollution problems due to the loss of geothermal fluid constituents and corrosion/scale control chemicals. Significant technical and economic tradeoffs exist among water quality, materials selection, and chemical treatments for cooling systems. Therefore, the use of geothermal fluid for cooling water is an issue with major implications for system costs and also for the feasibility of site development in many cases.

This brief discussion of geochemical engineering problems has not been exhaustive, but it is sufficient to illustrate the significance of the actual and potential problems. Many of these problems are interrelated and can be represented by a few fundamental R&D needs. As described later in this document, the federal program has been organized around these focal points to ensure a high R&D impact on the future productivity of the geothermal industry.

D. Rationale

The Geochemical Engineering Program has been derived in response to chemistry-related problems encountered in private sector attempts to commercialize geothermal energy. The lack of private sector R&D to address many of these problems has been associated with a lack of knowledge concerning the availability and utilization potential of geothermal energy, uncertain risks, high R&D investments required, insufficient market incentives, lack of adequately demonstrated utilization technology, and absence of an organized geothermal industry infrastructure.

Table 3 shows that industry efforts to establish a large number of viable geothermal wells between 1927 and 1965 met with one or more technical problems of scaling, loss of fluid temperature due to inflow of cold water, environmentally unacceptable waste disposal, and production declines. This generally unsuccessful record represents about \$40 million privately invested with virtually no return (assuming a cost of \$250,000 per well)(1). In addition to these problems, many examples of materials and component damage and failure can be cited which resulted from an inability to specify or obtain reliable materials or components for the particular chemical-thermal environment involved. Examples of these and other geochemistry-related problems experienced in geothermal development to date are contained in Table 4 and they demonstrate the need for long-range/high-payoff R&D organized to identify fundamental similarities among problems at different sites and to provide generic tools for site-specific problem solving.

(1) Reference 3.

TABLE 3
GENERAL GEOCHEMISTRY PROBLEMS EXPERIENCED
IN EARLY EXPLORATORY DRILLING IN U.S.

Site	Number of Wells Drilled	Dates Drilled	Problem
Salton Sea (Niland), CA	15 > 65	1927 1932-54 1957-65	Corrosion, scaling, waste disposal.
Brady Hot Springs, NV	9	1959-65	Inflow of cold water and scaling.
Beowawe, NV	11	1959-65	Inflow of cold water and scaling.
Steamboat Springs, NV	~ 36	1920-62	Severe scaling by CaCO ₃ , loss of production in days.
Clear Lake, CA	4	1961-64	Severe problem with waste disposal, 100 ppm boron.
Valles Caldera, Jemez Springs, Sulphur Springs, NM	4	1960-64	Decline of production with time.
Calistoga, CA	3	1960-61	Problems with disposal and scaling, erupting geyser well.
	<hr/> ~158 wells		

Source: Reference 3.

TABLE 4
SOME GEOCHEMISTRY-RELATED PROBLEMS EXPERIENCED
OR EXPECTED IN SITE-SPECIFIC DEVELOPMENTS

SITE	TYPE OF UTILIZATION SYSTEM ¹	LOCATION OF PROBLEM	DESCRIPTION OF PROBLEM	CAUSE OF PROBLEM
Raft River, ID	Electric, binary	Production wells	Failure of a number of downhole pumps	Miscellaneous causes, including adverse effects of fluid on pump materials
		Cooling system	Short expected service life of working fluid surface-contact condenser and reduced brine flow rates	Corrosion of inappropriately selected carbon steel condenser and scaling in the condenser (the cooling system uses aerated geothermal water).
East Mesa, CA	Electric, binary	Production well	Failure of a number of downhole pumps	Miscellaneous causes, including adverse effects of fluid on pump materials
		Energy conversion system	Cross-contamination of brine and working fluid streams	Inadequate design and/or operating procedures of heat exchange system
East Mesa, CA	Electric, binary downhole generator	Cooling system	Inappropriate carbon steel selected for working fluid condenser using aerated geothermal water for cooling	Similar to Raft River condenser problem, but developer here unaware of Raft River experience
East Mesa, CA	Electric, flash	Production well and energy conversion system	Scaling	Formation and precipitation of CaCO_3 in brine
East Mesa, CA	Desalination plant	Brine disposal (injection well)	Plugging of well	Excess solids in brine
Geysers, CA	Electric, steam	Energy conversion system	Failure of stainless steel diffusers in steam discharge muffler	Primarily chloride stress corrosion cracking; steam composition at time was unknown
		Cooling system	Serious corrosion of heat exchange surfaces	Use of aerated geothermal steam condensate as cooling water

¹May be only in pilot plant or planning stages.

TABLE 4 (Concluded)

SITE	TYPE OF UTILIZATION SYSTEM ¹	LOCATION OF PROBLEM	DESCRIPTION OF PROBLEM	CAUSE OF PROBLEM
Geysers, CA (Con't)	Electric, steam (Con't)	Brine and waste disposal	Surface disposal of steam condensate not allowed; abatement of H ₂ S produces large quantities of solid waste	Environmentally-unacceptable concentrations of NH ₃ and B in condensate
		Brine disposal (injection well)	Brine injected into old production well migrated into and cooled nearby producing well	Plugging of injection well in lower formations led to injected liquid entering permeable zones nearer surface
Baca, NM	Electric, flash		Final design review revealed many areas lacking appropriate engineering consideration	Limited operating experience with geothermal power plants and inadequate industry awareness of this experience
Salton Sea, CA	Electric, flash	Brine disposal (injection well)	Troublesome precipitation in well	Mixture of spent brines from two different production wells for injection resulted in BaSO ₄ precipitate from Ba ²⁺ in one brine from SO ₄ ²⁻ in another
Steamboat Springs, NV		Brine disposal (injection well)	Severe scaling in well	
Westmorland, CA		Brine disposal (injection well)	Loss of injectivity	
Clear Lake, CA		Brine disposal (surface disposal)	Environmentally-unacceptable brine	100 ppm boron
Brady Hot Springs, NV		Brine disposal (injection well)	Inflow of cold water and scaling	
Beowawe, NV		Brine disposal (injection well)	Inflow of cold water and scaling	
Klamath Falls, OR	Direct-heat, space heating	Energy conversion system	Leaks in copper tubing for supply lines and fan coils	Corrosion and scaling of inappropriate materials due to incomplete understanding of site geochemistry

¹May be only in pilot plant or planning stages.

The development of a comprehensive body of geochemical data is fundamental to any effort to evaluate the utility of standard materials and components in geothermal applications and, consequently, to identify areas where improved and/or new materials and component designs need to be provided. Baseline geochemical information is fundamental to devising efficient and safe fluid processing and handling techniques, i.e., selection of type of energy conversion system, identification and evaluation of required environmental controls, estimation of operating and maintenance costs, prediction of reservoir, well, and plant life, development of monitoring and instrumentation equipment, scale control services required, feasibility of using geothermal brine as cooling water, and so on. Since there is significant scope in the site-specific selection of the type of geothermal energy utilization system, specific components, and necessary system modifications, costly mistakes can occur if all relevant geochemical engineering problems are not identified.

As mentioned, the need to use geothermal brine for cooling water is becoming a critical issue in the future of geothermal energy in the U.S. as nationwide attention is focussed on protecting natural water supplies and on water conservation through the re-use of industrial wastewaters. The water quality and fluid handling problems involved in developing reliable geothermal cooling systems of this type will be addressed primarily by the Geochemical Engineering Program. Another significant problem related to maintaining the quality of water resources is the need for disposal of large quantities of brine that must, in most cases, be isolated from surface and subsurface water features. A 100 MWe power plant can produce 7-23 million gallons (20,000 - 70,000 acre feet) of wastewater a

year, depending on the temperature of the geothermal fluid. Since injection will be the dominant disposal method at geothermal electric sites, analysis of injection successes and failures to date, in conjunction with modeling studies to elucidate the behavior of injected fluids and the fluid-formation interactions, is vital for identifying efficient and economic injection locations and routines.

While there is no doubt that significant geochemical engineering problems exist and that the technical and economic feasibility of geothermal energy utilization is benefiting from federal R&D, there is a degree of difficulty involved in quantifying the impacts of the program. These impacts can apply to the fluid extraction process (drilling and operation of production wells), to the energy utilization process (primary energy conversion and support systems), or to the brine/waste disposal system (including the drilling and operation of injection wells).⁽¹⁾ The direct benefits of surmounting many of the identified problems have been mentioned in the preceding section. However, the savings that will be attained through implementation of the Geochemical Engineering Program are not limited to a few specific items, but will be found in a wide variety of areas which are often difficult to quantify in isolation. These include the reduction of downtime (which can cost \$100,000 per day for a commercial-scale plant due to lost power production and the hardware and manpower required to rectify the problem), reduction of operating and maintenance costs, increased component and system life, and increased well life.

(1) In some direct-heat applications, the energy conversion process can be moved to the downhole environment by the use of a downhole heat exchanger, which obviates the need for brine disposal.

The contribution of the Geochemical Engineering Program to the increased technical and economic feasibility of geothermal systems is sometimes difficult to distinguish from the impact of DGE's Geothermal Materials Program. In particular, the Geochemical Engineering Program provides the information required by the Geochemical Materials Program for evaluating materials-related needs. This process will lead to substantial cost savings by identifying where standard materials will provide adequate life and by aiding the development of improved and/or new materials as necessary for reliable and economic service.

The Geochemical Engineering Program is primarily a technical applied long-range research program for increasing industry productivity. It will facilitate the collection and analysis of geochemical data in areas where such information is lacking and where it is needed to secure improvements in geothermal utilization technology. "Dry"-steam and flash-steam technologies (at vapor-dominated and liquid-dominated resources, respectively) are relatively well-established, although there are areas where efficiency, reliability, and costs can be favorably impacted by the Geochemical Engineering Program. The economic utilization of the majority of the U.S. geothermal resource base will, however, depend on the ability to provide advanced conversion systems, especially binary technology, capable of exploiting moderate-temperature resources. The program will be a critical element in the development of this high-risk/high-payoff binary energy conversion technology, which is a major focus for federal support. Since there is not sufficient sustained operational experience with binary power plants in the U.S. from

which a significant body of knowledge can be derived, the Geochemical Engineering Program will be instrumental in assembling the requisite data for optimizing future design and operation of binary facilities.

Estimates of the cost impacts of the combined geochemical engineering and materials programs are available, though they do not consider all current federally-sponsored projects. Table 5 presents illustrative estimated impacts of geochemical engineering and materials R&D for 5,000 MWe, 15,000 MWe, and 25,000 MWe power-on-line scenarios (using simplified assumptions). These figures indicate that potential savings of up to \$1.6 billion on production wells costs and \$810 million on plant costs for the first 15,000 MWe developed could result from geochemical engineering and materials R&D. Capital cost savings have been estimated to be 2.2% for a steam plant, 5.5% for a flash plant, and 5.8% for a binary plant,⁽¹⁾ equating to \$1.3 - \$3.5 million for a "typical" plant cost of \$60 million. This could result in capital cost savings of \$390 - \$1,050 million for 15,000 MWe of generating capacity, depending on the precise mix of plant types that will be installed. Since the plant types for which the largest savings are possible (binary and flash) will predominate, it is logical to expect savings in the higher range of any such estimates.

Table 6 identifies component-specific productivity savings attributable to the combined impact of geothermal chemistry and materials research. The overall geochemical engineering and materials R&D benefit/cost ratio for electricity generation will, according to these estimates, range from a pessimistic 18.3 to an optimistic 39.8.⁽¹⁾

⁽¹⁾ Reference 4.

TABLE 5
ILLUSTRATIVE COST AND GEM PROGRAM SAVINGS
DATA FOR GEOTHERMAL ELECTRIC PLANTS

Geothermal Electric Generation (MWe)	5,000	15,000	25,000
No. of 50 MWe Plants Required	100	300	500
No. of Production Wells Required ⁽¹⁾	5,000	15,000	25,000
Cost of Plants @ \$60m/Plant (\$m)	6,000	18,000	30,000
Cost of Production Wells @ \$1m/Well(\$m)	5,000	15,000	25,000
GEM Reduction of Plant Cost @ 4.5% ⁽²⁾ (\$m)	270	810	1,350
GEM Reduction of Well Cost @ 11% ⁽³⁾ (\$m)	550	1,650	2,750

(1) Assumes drilling of 50 production wells per 50 MWe plant over plant life.

(2) Mean of MITRE Corporation estimates of savings for steam (2.2%), flash (5.5%), and binary (5.8%) plants, Source: Reference 4.

(3) Source: Reference 4.

TABLE 6
PERCENTAGE PLANT AND COMPONENT COST
SAVINGS DUE TO GEOCHEMICAL
ENGINEERING AND MATERIALS PROGRAM

Reduction of Plant Capital Costs:	<u>Plant</u>	<u>%</u>
	Steam	2.2
	Flash	5.5
	Binary	5.8
Reduction of Component Lifetime Costs:	<u>Component</u>	
	Heat exchanger	12.0
	Pressure vessel	18.7
	Gathering pipelines	28.9
	Downhole pump	38.3
Reduction of Component Capital Costs:	<u>Component</u>	
	Heat exchanger	9.7
	Pressure vessel	16.0
	Gathering pipelines (F&B plants)	22.2

Source: Reference 4.

The preceding figures do not include the favorable impacts which will be attainable for production wells and energy conversion facilities for geothermal direct-heat applications, although there is significant scope for technology overlap between electric and direct-heat uses. They also exclude additional wells for injection which could number about 12 wells per 50 MWe plant over its lifetime (assuming no old production wells are used for injection disposal) and which are also a target for significant cost savings.

Table 7 lists the benefit/cost ratio ranges estimated for eight areas of federally-funded R&D within the Geochemical Engineering Program. Table 8 presents specific examples of the levels of savings that may be expected from the program. The various individual benefits of the Geochemical Engineering Program can be condensed into three generic technical areas as shown in Table 9; the total reduction in the cost of generating 25,000 MWe from hydrothermal resources is estimated to range from 1.84% to 4.44%.

Not all of the program projects are hardware-oriented, but they all will contribute to providing the data, procedures, and equipment necessary for geochemistry problem solving. The Geochemical Engineering Program will be instrumental in deriving a generic long-range approach to geothermal chemistry-related problems from an evaluation of existing U.S. and international experience in geothermal energy.

E. Objectives

In order for DGE to implement its strategy, objectives have been developed to guide problem identification, project selection and

TABLE 7

**BENEFIT/COST RATIOS FOR SOME SPECIFIC GEOCHEMICAL
ENGINEERING PROGRAM R&D AREAS ***

R&D AREA	Benefit/Cost Ratio ¹	
	Pessimistic	Optimistic
Prediction of fluid scaling tendency	72.7	132.3
In-line scaling study	72.7	132.3
Study of silica precipitation mechanism	0	1.9
Scale control	0	28.3
Sampling and analysis	27.4	41.5
Instrumentation	3.5	79.9
Brine disposal	30.9	56.9
Waste utilization	261.2	324.4
Entire GEM Program ²	18.3	39.8

* Includes impacts of work completed prior to 1978.

¹Excludes sunk costs.

²Totals are not additive.

Source: Reference 5.

TABLE 8

SOME SAVINGS ATTAINABLE THROUGH THE
GEOCHEMICAL ENGINEERING PROGRAM

IMPACTED AREA	% SAVING
Preconstruction engineering, capital cost	2.9-6.6
Instrumentation, capital cost	(0-2)
Production well, O&M cost	0-16.2
Injection well life	5-15
Energy conversion plant, O&M cost	0-3.5
Spent brine treatment, O&M cost	80-100
Deep well pump, O&M cost	5-9

Source: Reference 5.

TABLE 9
SUMMARY OF BENEFITS OF GEOCHEMICAL
ENGINEERING R&D

Impacted Technical Area	Benefit/Cost Ratio ¹		Cost Reduction (%)
	Pessimistic	Optimistic	
Precipitation and Geochemistry	22.0	42.9	0.67-1.30
Measurement, Testing, and Process Control Technology	7.4	54.1	0.25-1.84
Waste Management	16.4	23.2	0.92-1.30
TOTAL			1.84-4.44

¹Excludes sunk costs.

Source: Reference 5.

prioritization, assessment of the need for government involvement, and determination of the amount and distribution of funding. The major objectives are, through support and coordination of private sector projects, to:

- (1) identify long-term generic geochemistry-related problems affecting geothermal energy utilization, and plan and coordinate appropriate remedial applied R&D programs;
- (2) review fluid management techniques and make recommendations as appropriate; and
- (3) disseminate technical information to the geothermal community in a timely manner in order to minimize duplication of effort and maximize the return on R&D investments.

When the need arises, as determined from interaction with a wide range of industry representatives, the program will assist the private sector with funding to:

- (1) develop and apply sampling and analysis techniques suitable for site-specific characterization of the chemical and thermal properties of geothermal fluids;
- (2) develop simulation codes for the elucidation and prediction of geothermal fluid behavior in downhole, energy conversion, and cooling system environments;
- (3) develop prototype high-performance sensors and instrumentation for reliable geothermal service;
- (4) assess process-engineering requirements for efficient and safe fluid extraction and energy conversion and design components and systems accordingly;

- (5) evaluate brine and waste treatment/disposal options;
- (6) investigate the viability of byproduct recovery from brines and other wastes as a means of reducing pollution loads and/or achieving greater overall system economy;
- (7) evaluate existing alternative cooling systems and, where necessary, design integrated cooling systems compatible with geothermal and/or working fluids; and
- (8) investigate and identify generic methods for the control of problem precipitation and scale formation in geothermal systems.

III. PROGRAM ORGANIZATION

A. Program Structure and Objectives of Program Elements

The strategy of the Geochemical Engineering Program is implemented through an applied R&D capability organized according to the four major areas of concern. These areas of concern, or program elements, are:

- (1) Fluid Characterization - developing and standardizing fluid sampling and analysis methods; conducting fluid inventory; and characterizing geothermal fluids.
- (2) Geochemical Monitoring and Control - developing, testing, and refining prototype high-performance in-line chemical sensors and instrumentation for well and plant applications.
- (3) Fluid Handling - evaluating and modifying component and system design and operation; evaluating brine and waste treatment/disposal options; evaluating and developing precipitation and scale control techniques; designing cooling systems for operation with geothermal and working fluids; collecting geochemical data; modeling of fluid process chemistry.
- (4) Technology Transfer - preparing and publishing handbooks, technical reports, and newsletters; organizing conferences and workshops; involving professional societies in standards development; cooperative programs.

The four program elements are composed of discrete subelements as detailed in Table 10.

The objectives of the program elements are briefly described below.

1. Fluid Characterization

The determination of the chemical composition and thermal properties of geothermal fluids is a vital function in evaluating the national geothermal

TABLE 10

GEOCHEMICAL ENGINEERING PROGRAM ELEMENTS AND SUBELEMENTS

1. FLUID CHARACTERIZATION
 - (1) Sampling and analysis methods development
 - (2) Plant fluid characterization
 - (3) Fluid inventory
2. GEOCHEMICAL MONITORING AND CONTROL
 - (1) Sensor development
 - (2) Plant instrumentation
 - (3) Down-well instrumentation
3. FLUID HANDLING
 - (1) Solids and scale control
 - (2) Plant unit operations and operating procedures
 - (3) Fluid disposal
 - (4) Integrated waste treatment and byproduct recovery
 - (5) Integrated cooling water systems
 - (6) Modeling of fluid process chemistry
4. TECHNOLOGY TRANSFER
 - (1) Handbooks
 - (2) Manuals
 - (3) Conferences and workshops
 - (4) Newsletters
 - (5) Professional societies interaction
 - (6) Product technology commercialization
 - (7) New standards

resource base. This program element is designed to fulfill this need by establishing appropriate standardized fluid sampling and analysis methods, compiling the results of characterization studies of specific resources for reference and planning purposes, and by organizing, monitoring, and reviewing relevant case studies at geothermal power plant facilities.

2. Geochemical Monitoring and Control

The objective of this program element is to develop, as necessary, prototype in-line chemical sensors and instrumentation that can perform reliably and accurately in the high-temperature and chemically-aggressive geothermal environments posed by both downhole and plant operating conditions. The field testing of this instrumentation will verify the technical performance of instrumentation packages, collect valuable geochemical data under plant operating conditions, help identify plant design and operational problems, and permit the design of integrated plant fluid monitoring systems. Existing commercially-available monitoring and control equipment has not generally been designed for such severe environments and has proved inadequate for geothermal applications to date.

3. Fluid Handling

R&D is required to address problems in a number of fluid handling areas in order to ensure technical feasibility and environmental acceptability of geothermal systems. The objective is to evaluate existing technologies, including those used in non-geothermal energy and chemical applications, for all phases of geothermal fluid handling and processing. Special consideration has been allocated to precipitation and scale control, brine treatment/disposal, non-brine waste treatment/disposal, cooling water systems, and fluid process chemistry modeling.

4. Technology Transfer

The objective of the technology transfer element is to facilitate the rapid and accurate dissemination of information to concerned parties within the geothermal community and service/supply industries. It is imperative that project plans, accomplishments, and products be made available to others involved in geothermal development so that (1) adequate technology and methods already available can be effectively utilized, (2) duplication of effort can be avoided, (3) R&D can build on previous experiences, and (4) problem areas requiring particular attention can be readily identified. Explicit channels for information and technology transfer allow maximization of R&D impact and efficient formulation of new plans. An important aspect of this element is the cooperative programs arranged to transmit, in an interactive manner, technology, information, and new ideas from companies and universities conducting R&D to geothermal developers, equipment manufacturers, and supply/service companies. Professional societies are also involved in this area, particularly for the development of new standards. Technology/information transfer also has a role to play in identifying educational and training needs and building public awareness and support of geothermal energy.

B. PROGRAM PRIORITIES AND FUNDING

The priorities for each element and subelement in the program were determined by DGE, with industry input, on the basis of four major evaluation criteria:

- (1) Cost Impact - This is a measure of the favorable impact the subelement can have on the long-range productivity of the geothermal industry.

Increased systems efficiencies and operational reliabilities will result

in varying reductions in field, development, and operating and maintenance costs compared to currently prevailing estimates and practices.

- (2) Environmental Concern - This criterion is an indication of the degree to which the subelement will contribute to the controlled and safe handling of geothermal fluids and gases at high temperature and pressure and of any accompanying process wastes.
- (3) State-of-Knowledge - This refers to the extent to which the subelement will expand existing data and know-how and thereby improve the performance of systems by assuring proper system design, timeliness in problem identification, and complete delineation of all problems that might constrain development.
- (4) Technology Shortfall - In many cases, the growing geothermal industry does not represent sufficient demand for the process engineering and chemical services industries to undertake development of new or improved technology. The specified subelement will have some impact on providing the means to make needed long-range technology available.

Table 11 shows the relative impacts of each of the program elements according to the above criteria and the overall priority within the program assigned to the elements. Tables 12 through 15 present the relative impacts, priorities, and funding of the subelements. Much of this work may be funded through private sector programs.

TABLE 11
GEOCHEMICAL ENGINEERING PROGRAM
ELEMENT PRIORITIES

ELEMENT	EVALUATION CRITERIA				PRIORITY
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF- KNOWLEDGE	TECHNOLOGY SHORTFALL	
Fluid Characterization	2	2	1	2	2
Geochemical Monitoring and Control	1	1	1	1	1
Fluid Handling	1	1	2	2	1
Technology Transfer	2	2	2	2	2

1 = High

2 = Medium

3 = Low

TABLE 12
FLUID CHARACTERIZATION:
ELEMENT PRIORITIES AND FUNDING

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL*
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	TECHNOLOGY SHORTFALL		
Sampling and Analysis Methods Development	2	1	2	2	2	3
Plant Fluid Characterization	1	3	1	2	1	1
Fluid Inventory	3	2	2	3	3	3

FUNDING LEVEL (1978 \$)

1 = High = \$ 2.0 - 3.5 M

2 = Medium = \$ 0.8 - 1.2 M

3 = Low = \$ 0.2 - 0.6 M

*Represents combined industrial and federal funding.

TABLE 13

**GEOCHEMICAL MONITORING AND CONTROL:
ELEMENT PRIORITIES AND FUNDING**

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL*
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	TECHNOLOGY SHORTFALL		
Sensor Development	1	2	1	1	1	2
Plant Instruments	1	2	2	2	1	2
Down-well Instruments	2	2	1	1	2	2

FUNDING LEVEL (1978 \$)

1 = High = \$ 2.0 - 3.5 M

2 = Medium = \$ 0.8 - 1.2 M

3 = Low = \$ 0.2 - 0.6 M

*** Represents combined industrial and federal funding.**

TABLE 14

**FLUID HANDLING:
ELEMENT PRIORITIES AND FUNDING**

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL*
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	TECHNOLOGY SHORTFALL		
Solids and Scale Control	1	2	2	2	1	1
Plant Unit Operations and Operating Procedures	3	3	2	2	3	2
Fluid Disposal	1	1	2	1	1	1
Integrated Waste Treatment and Byproduct Recovery	2	2	3	2	2	1
Integrated Cooling Water Systems	1	1	2	2	1	1
Modeling of Fluid Process Chemistry	2**	1	2	2	2	3

FUNDING LEVEL (1978 \$)

1 = High = \$ 2.0 - 3.5 M

2 = Medium = \$ 0.8 - 1.2 M

3 = Low = \$ 0.2 - 0.6 M

* Represents combined industrial and federal funding.

** Main impact on wellbore and reservoir.

TABLE 15
TECHNOLOGY TRANSFER:
ELEMENT PRIORITIES AND FUNDING

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL*
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	TECHNOLOGY SHORTFALL		
Handbooks	2	2	2	2	2	2
Manuals	2	2	2	1	2	3
Conferences and Workshops	3	2	2	2	3	3
Newsletters	3	3	2	2	2	3
Professional Societies Interaction	2	3	2	2	2	3
Product Technology Commercialization	1	3	2	1	1	1
New Standards	2	2	2	2	2	2

FUNDING LEVEL (1978 \$)

1 = High = \$ 2.0 - 3.5 M

2 = Medium = \$ 0.8 - 1.2 M

3 = Low = \$ 0.2 - 0.6 M

* Represents combined industrial and federal funding.

Estimated federal funding for the Geochemical Engineering Program for the period 1978 - 1988 is approximately \$10 million; this is broken down by program elements in Figure 5. Estimated funding levels for the identified industry requirements on a yearly basis over the 1976 - 1988 time period are shown in Figure 6. These figures should be regarded only as a relative guide to technical areas for R&D emphasis. It should be noted that the early period of DGE geochemical engineering related R&D activity effectively initiated the outreach program with an increasing number of university and industrial contracts vis-a-vis direct national laboratory support projects.

C. Program Management

The implementation of the Geochemical Engineering Program is administered primarily through the Division of Geothermal Energy and its field offices. A Technical Coordinator (from either a national laboratory or an industrial firm) designated by DOE is associated with each program element. The Technical Coordinator exercises overall responsibility for managing and subcontracting the work within his program element. However, not all aspects of a program element may come under the direct control of the coordinator due, for example, to the nature of particular funding/contracting arrangements. The coordinator works closely with professional societies or technical advisory groups consisting of industrial and university experts. For the Geochemical Engineering Program, Battelle Pacific Northwest Laboratories serves as the Technical Coordinator for the fluid characterization and monitoring/control program elements and Los Alamos Scientific Laboratory for the fluid handling element, while DOE directly manages the technology transfer program element since this function is common to the other three activity areas of the program.

FIGURE 5
ESTIMATED PROGRAM ELEMENT
FUNDING, 1978-1988

FIGURE 6

FUNDING REQUIREMENTS FOR IDENTIFIED
INDUSTRY AND GOVERNMENT PROGRAMS
1978 - 1988

An important aspect of the Geochemical Engineering Program is the interaction with geothermal or chemistry-oriented groups and the involvement of professional societies in the R&D evaluation process. The Geochemical Engineering Program manager interfaces directly with other concerned offices within DOE and with interagency groups such as the Committee on Materials and Technology (COMAT) through the Energy Materials Coordinating Committee. Professional and trade societies and other parties are brought into consultation by membership in those groups. Organizations taking part in this way include the American Petroleum Institute (API), American Society for Testing and Materials (ASTM), Water Pollution Control Federation, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Geothermal Resources Council (GRC), Society of Petroleum Engineers (SPE), and the DOE Consumer Advisory Committee.

IV. PROGRAM STATUS

Specific efforts organized within the Geochemical Engineering Program address important technical long-range/high-risk applied R&D needs identified earlier in this report. Table 16 lists completed and active projects by title and contractor and indicates the subelements which each project concentrates on or can be expected to affect to a significant degree. All of the projects address two or more subelements. However, the relative importance of the individual subelements is not necessarily reflected in the number of projects attributed to them since some of the projects are only of secondary relevance to certain subelements (Tables 12-15 should be consulted for a priority ranking of subelements).

The following four subsections list and briefly describe the projects completed and underway and set out the plans and milestones for each of the four program elements. A final subsection describes significant accomplishments to date.

A. Fluid Characterization

Completed Projects

- (1) A Compilation of Data on Fluids from Geothermal Resources in the U.S.

Lawrence Berkeley Laboratory

Report No. LBL-5936

The purpose of this compilation was to provide information on the chemistry of geothermal fluids to scientists and engineers involved with the development of liquid-dominated geothermal resources. The compilation is a comprehensive tabulation of available geothermal fluid data from the most important geothermal resources in the United States and is stored in a computerized information retrieval database.

- (2) Assessment of the Characterization (in situ-Downhole) of Geothermal Brines

National Materials Advisory Board, National Academy of Sciences

Report No. NMAB-344

TABLE 16

MATRIX OF COMPLETED AND ACTIVE PROJECTS AND ADDRESSED SUBELEMENTS

PROGRAM SUBELEMENTS PROJECTS		FLUID CHARACTERIZATION			MONITORING AND CONTROL			FLUID HANDLING					TECHNOLOGY TRANSFER							
		SAMPLINGS & ANALYSIS METHODS DEVELOPMENT	PLANT FLUID CHARACTERIZATION	FLUID INVENTORY	SENSOR DEVELOPMENT	PLANT INSTRUMENTATION	DOWN-WELL INSTRUMENTATION	SOLIDS AND SCALE CONTROL	UNIT OPERATIONS & OPERATING PROCEDURES	FLUID DISPOSAL	WASTE TREATMENT & BYPRODUCT RECOVERY	COOLING WATER SYSTEMS	MODELING OF FLUID PROCESS CHEMISTRY	HANDBOOKS	MANUALS	CONFERENCES AND WORKSHOPS	NEWSLETTERS	PROFESSIONAL SOCIETIES INTERACTION	PRODUCT TECHNOLOGY COMMERCIALIZATION	NEW STANDARDS
Binary Plant Fluid Case Study (PNL)		X	X	X	X	X		X	X	X		X	X			X		X		
Field Testing of Monitoring Instruments (PNL)			X	X	X	X		X	X	X		X				X		X	X	
Sampling And Analysis Methods Development (PNL)		X	X	X				X		X		X	X		X	X		X		X
Precipitation and Scale Control for Salton Sea Brines (LLL)		X	X	X				X		X		X	X			X		X	X	
Chemical Management Techniques Development (LLL)		X	X	X				X	X	X		X				X		X		
Processing of Brines for Injection (LLL)		X	X	X				X	X	X	X		X			X		X	X	
Study of Using Surface Waters to Supplement Injection (LLL)		X	X	X				X		X	X	X	X			X		X		
Measurement of Injectability of Brines (LLL)		X	X	X				X		X	X		X			X		X		
Development of Reference Electrode (PNL)					X	X	X									X		X	X	
Development of Conductivity Probe (PNL)					X	X	X	X								X		X	X	
Development of Rodox Probe (PNL)					X	X	X	X								X		X	X	

TABLE 16 (Continued)

PROGRAM SUBELEMENTS PROJECTS	FLUID CHARACTERIZATION			MONITORING AND CONTROL			FLUID HANDLING						TECHNOLOGY TRANSFER						
	SAMPLING & ANALYSIS METHODS DEVELOPMENT	PLANT FLUID CHARACTERIZATION	FLUID INVENTORY	SENSOR DEVELOPMENT	PLANT INSTRUMENTATION	DOWN-WELL INSTRUMENTATION	SOLIDS AND SCALE CONTROL	UNIT OPERATIONS & OPERATING PROCEDURES	FLUID DISPOSAL	WASTE TREATMENT & BYPRODUCT RECOVERY	COOLING WATER SYSTEMS	MODELING OF FLUID PROCESS CHEMISTRY	HANDBOOKS	MANUALS	CONFERENCES AND WORKSHOPS	NEWSLETTERS	PROFESSIONAL SOCIETIES INTERACTION	PRODUCT TECHNOLOGY COMMERCIALIZATION	NEW STANDARDS
Development of Corrosion Ratometer (PNL)				X	X	X	X								X		X	X	
Standard Electrode (SRI)				X	X	X									X		X	X	
Development of High-Tempera- ture Glass pH Sensor (Leeds & Northrop)				X	X	X	X					X			X		X	X	
Development of High-Tempera- ture Glass pH Sensor (Owens Illinois)				X	X	X	X					X			X		X	X	
Development of High-Tempera- ture Ceramic pH Sensor (General Electric)				X	X	X	X					X			X		X	X	
Development of High-Tempera- ture Chemically Sensitive Semiconductor (U. of PA)	X			X	X	X	X					X			X		X	X	
Development of High-Tempera- ture CO ₂ Sensor (Leeds & Northrop)	X			X	X	X	X					X			X		X	X	
Development of High-Tempera- ture Sulfide Sensor (Beckman Instruments)	X			X	X	X	X					X			X		X	X	
R&D of Cavitation Descaling Techniques for Heat Exchanger Tubes Used in Geothermal Energy Plants (Daedalean Assocs.)							X		X	X	X				X		X		

TABLE 16 (Continued)

PROGRAM SUBELEMENTS PROJECTS		FLUID CHARACTERIZATION			MONITORING AND CONTROL			FLUID HANDLING						TECHNOLOGY TRANSFER						
		SAMPLING AND ANALYSIS METHODS DEVELOPMENT	PLANT FLUID CHARACTERIZATION	FLUID INVENTORY	SENSOR DEVELOPMENT	PLANT INSTRUMENTATION	DOWN-WELL INSTRUMENTATION	SOLIDS AND SCALE CONTROL	UNIT OPERATIONS & OPERATING PROCEDURES	FLUID DISPOSAL	WASTE TREATMENT & BYPRODUCT RECOVERY	COOLING WATER SYSTEMS	MODELING OF FLUID PROCESS CHEMISTRY	HANDBOOKS	MANUALS	CONFERENCES AND WORKSHOPS	NEWSLETTERS	PROFESSIONAL SOCIETIES INTERACTION	PRODUCT TECHNOLOGY COMMERCIALIZATION	NEW STANDARDS
Geochemistry Modeling & Fluid Chemistry (LASL)			X	X					X	X	X		X			X		X		
Solubility of SrSO ₄ in Aqueous Solutions (Vetter Research)				X				X		X			X			X		X		
Geothermal Brine Modeling (UCSD)			X					X	X	X	X	X	X			X		X		
Short-Term Pilot Cooling Tower Tests (EG&G)		X						X	X			X				X		X		
Calorimetry of Geothermal Fluids and Related Materials (Arizona State U.)								X	X	X	X	X	X			X		X		
Calorimetric Determination of the Entropies and Gibbs Free Energies of Formation of Selected Scale-Forming Minerals (USGS)								X	X	X	X	X	X			X		X		
Solubility and Kinetics of Precipitation of Minerals of Importance in Geothermal Applications (U. of NY, Buffalo)								X	X	X	X	X	X			X		X		
Hydrodynamic/kinetic Reactions and Morphology Changes of Scale Forming Materials (U. of Delaware)								X	X	X	X	X	X			X		X		

TABLE 16 (Continued)

PROGRAM SUBELEMENTS PROJECTS	FLUID CHARACTERIZATION			MONITORING AND CONTROL		FLUID HANDLING							TECHNOLOGY TRANSFER						
	SAMPLING & ANALYSIS METHODS DEVELOPMENT	PLANT FLUID CHARACTERIZATION	FLUID INVENTORY	SENSOR DEVELOPMENT	PLANT INSTRUMENTATION	DOWN-WELL INSTRUMENTATION	SOLIDS AND SCALE CONTROL	UNIT OPERATIONS & OPERATING PROCEDURES	FLUID DISPOSAL	WASTE TREATMENT & BYPRODUCT RECOVERY	COOLING WATER SYSTEMS	MODELING OF FLUID PROCESS CHEMISTRY	HANDBOOKS	MANUALS	CONFERENCES AND WORKSHOPS	NEWSLETTERS	PROFESSIONAL SOCIETIES INTERACTION	PRODUCT TECHNOLOGY COMMERCIALIZATION	NEW STANDARDS
Injection Well Stimulation Chemistry (Vetter Research)	X						X	X	X			X	X		X		X		
Precipitation and Scaling in Dynamic Geothermal Systems (ORNL)	X						X	X	X		X	X			X		X		
Silica Scaling Study (EIC Corp.)							X	X	X	X	X	X			X		X		
Silica Scale Kinetics (LBL)							X		X										
Scale Formation and Sup- pression (Dow)							X	X	X	X	X				X		X		
Scale Inhibition Test (Vetter Research)	X		X				X		X						X		X		
Geochemistry of Geothermal Systems (Penn. State)							X	X	X	X	X	X			X		X		
Compilation of Data on Geo- thermal Fluids (LBL)	X		X												X				
Assessment of the Charac- terization (in situ-downhole) of Geothermal Brines (NAS)	X			X	X	X	X	X	X	X	X						X		
Hydrodynamic/Kinetic Reactions in Liquid-Dominated Geothermal Systems (Aerojet)			X				X	X			X	X			X		X		

TABLE 16 (Concluded)

PROGRAM SUBELEMENTS PROJECTS		FLUID CHARACTERIZATION			MONITORING AND CONTROL			FLUID HANDLING					TECHNOLOGY TRANSFER						
		SAMPLING & ANALYSIS METHODS DEVELOPMENT	PLANT FLUID CHARACTERIZATION	FLUID INVENTORY	SENSOR DEVELOPMENT	PLANT INSTRUMENTATION	DOWN-WELL INSTRUMENTATION	SOLIDS AND SCALE CONTROL	UNIT OPERATIONS & OPERATING PROCEDURES	FLUID DISPOSAL	WASTE TREATMENT & BYPRODUCT RECOVERY	COOLING WATER SYSTEMS	MODELING OF FLUID PROCESS CHEMISTRY	HANDBOOKS	MANUALS	CONFERENCES AND WORKSHOPS	NEWSLETTERS	PROFESSIONAL SOCIETIES INTERACTION	PRODUCT TECHNOLOGY COMMERCIALIZATION
National Society Workshops (LASL)		X	X	X	X	X	X	X	X	X	X	X			X		X		X
Scale Management Conference, 1976		X			X	X	X	X	X		X				X		X		
Fluid Management Workshop, 1977		X	X	X	X	X	X	X	X	X	X	X			X		X		X
Mineral Recovery-Fluid Management Coordination Meetings, 1976, 1977		X	X	X	X	X	X	X	X	X	X	X			X		X		
Workshop on Scale Control in Geothermal Energy Extraction Systems, 1977					X	X	X	X	X	X	X	X			X		X		
Workshop on Scale Control in Geothermal Systems, 1980					X	X	X	X	X		X				X		X		
International Information Exchange		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

The objectives of this study were to identify and quantify the physical and chemical properties which characterize geothermal fluids and identify the downhole instrumentation needed to monitor changes in the values of these characteristics.

Current Projects

(1) Sampling and Analysis Methods Development

Battelle Pacific Northwest Laboratories

The objective is to improve geothermal data reliability/comparability, improve geothermal analytical capability, provide a basis for standard sampling and analysis method selection, eliminate irrelevant analyses, and establish an ASTM group to develop consensus standards. The work includes round robin comparisons between industrial, university, EPA, USGS, and national laboratory chemists. This will survey available methods of analysis, identify elements of interest, relate end uses of data to an analytical program, and test best methods at East Mesa.

(2) Binary Plant Fluid Case Study

Battelle Pacific Northwest Laboratories

The objective is to monitor and analyze the chemistry, scale deposition, and materials performance of the Magma binary plant at East Mesa in order to develop a working knowledge of geothermal fluid process chemistry for achieving optimum utilization and future plant designs.

Milestones

The major milestones shown in Figure 7 are proposed as a guide for orderly and effective development of private sector R&D as outlined in this report.

FIGURE 7

MAJOR FLUID CHARACTERIZATION MILESTONES

B. GEOCHEMICAL MONITORING AND CONTROL

Completed Projects

(1) Chemical Measurement Techniques Development

Lawrence Livermore Laboratory

This project is specifically tailored to the development of certain measuring techniques for Salton Sea brines, including a sampling probe, analytical technique for following SiO_2 precipitation rate, application of laser particle counting techniques, techniques for brine injection testing, and electrochemical corrosion rate measurement.

(2) Standard Electrode Development

Stanford Research Institute

A reference electrode is to be developed against which other instrumentation can be compared and calibrated in order to ensure reliability of measurements.

Current Projects

(1) Development of Reference Electrode

Battelle Pacific Northwest Laboratories

As SRI project above.

(2) Development of Conductivity Probe

Battelle Pacific Northwest Laboratories

This will develop a conductivity probe that can be used to detect flashing in heat exchangers which would reduce system efficiency due to scaling.

(3) Development of Redox Probe

Battelle Pacific Northwest Laboratories

The objective is to obtain a probe to detect the presence of oxygen in fluid streams in order to permit the prediction and prevention of corrosion episodes.

(4) Development of Corrosion Ratemeter

Battelle Pacific Northwest Laboratories

The objective is to develop a device for detecting corrosion and measuring corrosion rates in order to exercise better process control and prevent corrosion-related failures.

(5) Development of High-Temperature Glass pH Sensor

Leeds and Northrup

The purpose is to develop, fabricate, and test a glass electrode for measuring pH in brines at minimum conditions of 250°C and 5,000 psi in both downhole and above-ground environments.

(6) Development of High-Temperature Glass pH Sensor

Owens Illinois

As Leeds and Northrup project above.

(7) Development of High-Temperature Ceramic pH Sensor

General Electric Company

The objective is to develop a ceramic sensor for pH measurements over 250°C and 5,000 psi pressure.

(8) Development of High-Temperature Chemically Sensitive Semiconductor

University of Pennsylvania

This will develop an advanced, rugged, and small sensor to simultaneously measure several ionic species in brine.

(9) Development of High-Temperature CO₂ Sensor

Leeds and Northrup

The objective is to provide a sensor for in-line measurement of CO_2 at over 250°C and 5,000 psi in downhole and surface systems; such monitoring is crucial to turbine design and performance and to preventing scaling.

(10) Development of High-Temperature Sulfide Sensor

Beckman Instruments

This development of a sulfide ion sensor for conditions above $250^\circ\text{C}/5,000$ psi will be useful in predicting scaling, probability of atmospheric emissions, and corrosion.

(11) Field Testing of Monitoring Instruments

Battelle Pacific Northwest Laboratories

The in-line chemical monitoring instruments that will be developed and laboratory tested for geothermal applications under the preceding ten projects will be installed and tested in an actual plant to evaluate their accuracy, reliability, and field suitability.

Milestones

The major milestones shown in Figure 8 are proposed as a guide for orderly and effective development of private sector R&D as outlined in this report.

FIGURE 8

MAJOR GEOCHEMICAL MONITORING AND CONTROL MILESTONES

ACTIVITY		GEOCHEMICAL MONITORING AND CONTROL																										
TASK		CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
		FY 1980	FY 1980	FY 1980	FY 1981	FY 1981	FY 1981	FY 1982	FY 1982	FY 1982	FY 1983	FY 1983	FY 1983	FY 1984	FY 1984	FY 1984	FY 1985	FY 1985	FY 1985	FY 1986	FY 1986	FY 1986	FY 1987	FY 1987	FY 1987	FY 1988	FY 1988	FY 1988
Magma Plant Case Study							▽																					
Transducer Development																												
pH Sensor (Glass)					Fabrication	▽		▽	Lab. Tests																			
CO ₂ Sensor					Design	▽		▽	Lab. Tests																			
Sulfide Ion Sensor					Design	▽		▽	Lab. Tests																			
Chemically-sensitive Semiconductor							Design	▽				▽	Lab. Tests															

FIGURE 8

MAJOR GEOCHEMICAL MONITORING AND CONTROL MILESTONES

(Continued)

ACTIVITY									
GEOCHEMICAL MONITORING AND CONTROL									
TASK	CY 1980	CY 1981	CY 1982	CY 1983	CY 1984	CY 1985	CY 1986	CY 1987	CY 1988
	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988
Prototype Instruments Field Testing				pH △	CO ₂ △ Sulfide △	Semiconductor △	Completion of field tests ▽		
Downhole Sampler Development					△		▽		

C. FLUID HANDLING

Completed Projects

(1) Precipitation and Scale Control for Salton Sea Brines

Lawrence Livermore Laboratory

The objective is to test available chemical additives, both commercial antiscalants and other selected chemicals not specifically intended for precipitation/scale control, in order to identify effective or promising additives for the predominantly silica precipitation and scaling in Salton Sea brines.

(2) Precipitation and Scaling in Dynamic Geothermal Systems

Oak Ridge National Laboratory

The objective was to collect basic scaling data for model development and to develop scaling models for application in pilot plants.

(3) Silica Scaling Study

EIC Corporation

This effort collected data and prepared models for silica scaling and kinetics in geothermal brines.

(4) Scale Formation and Suppression

Dow Chemical Co.

The objective of this study was to evaluate scale control methods for heat exchangers and to provide experimental testing of fluid chemistry models developed by LASL in order to identify R&D needs for scale inhibitors and to provide quantitative data on scaling and scaling rates in pilot plant size equipment. This was accomplished by evaluating commercial scale inhibitors, several chemical approaches, and commercially-available scale inhibitor

equipment in synthetic geothermal waters and by measuring scaling rates and heat exchange coefficients for known input chemistries and system parameters.

(5) Silica Scale Kinetics

Lawrence Berkeley Laboratory

The objective was to study and document the kinetics of silica scaling in geothermal conditions to enhance understanding and control of the scaling process.

(6) Scale Inhibition in Geothermal Operations - Experiments with Dequest 2060 Phosphonate in Republic's East Mesa Field

Vetter Research

Report No. 79-5-27

This project had the objective of testing commercially-available scale-control additives for CaCO_3 scale at the East Mesa geothermal field to evaluate technical additive effectiveness, any undesirable side effects, and the economics of use at that site.

(7) Research and Development of Cavitation Descaling Techniques for Heat Exchanger Tubes Used in Geothermal Energy Plants

Daedalean Associates

The objective was to develop and field test cost-effective means of cavitation descaling for surface equipment.

(8) Short-Term Pilot Cooling Tower Tests

EG&G

Report No. EGG-FM-5087

The objectives of this project were to collect corrosion and scaling data and to identify and evaluate methods for corrosion and scale control for cooled geothermal water used as coolant in DOE's Raft River 5 MWe pilot plant.

(9) Study of Using Surface Waters to Supplement Injection

Lawrence Livermore Laboratory

This investigation intends to evaluate the feasibility of using local surface waters as make-up water for injection at the Salton Sea geothermal resource.

(10) Processing of Brines for Injection

Lawrence Livermore Laboratory

The objective was to develop and demonstrate a process for treating Salton Sea brine effluents that will produce wastes with high injectability and that will not significantly impair injection wells.

(11) Measurement of Injectability of Brines

Lawrence Livermore Laboratory

The objective of this project is to assess the injectability of brine at Imperial Valley resources by measuring the flow of brine through media that simulate downhole injection formations and correlating these measurements, as far as possible, with actual injection performance.

(12) Solubility of SrSO_4 in Aqueous Solutions

Vetter Research

The solubility of SrSO_4 is being determined in NaCl-free solution of CaCl_2 and MgCl_2 at 75°C and 95°C in order to identify solubility-temperature trends. Work will also be conducted with higher temperature solutions containing NaCl.

(13) Hydrodynamic/Kinetic Reactions in Liquid-Dominated Geothermal Systems

Aerojet Energy Conversion Co.

This project is evaluating how geothermal scale buildup occurs, and what hydrodynamic/kinetic mechanisms are operant during the scaling process. It identifies methods of controlling or modifying solids deposition in order to expand the utility of hydrothermal energy conversion systems. A mobile test unit was built and operated to perform a systematic evaluation of the interaction between hydrodynamics and the precipitation kinetics and morphology of solids.

(14) Calorimetric Determination of the Entropies and Gibbs Free Energies of Formation of Selected Scale-Forming Minerals

U.S. Geological Survey, Reston

The heat capacities of chalcopyrite (CuFeS_2), siderite (FeCO_3), rhodochrosite (MnCO_3), fayalite (Fe Si O_4), and tephroite (Mn Si O_4) between 5 and 600K were measured by combined adiabatic calorimetry and differential scanning calorimetry. Also measured will be the enthalpies of formation of siderite and rhodochrosite by HCl solution calorimetry. Thermodynamic scrubbing products were derived as a function of temperature and limits to scrubbing products for iron-rich amorphous silica were set.

(15) Solubility and Kinetics of Precipitation of Minerals of Importance in Geothermal Applications

State University of New York, Buffalo

Thermodynamic solubilities and kinetics of minerals of importance in geothermal scale formation, such as the calcium carbonate polymorphs, calcium sulfate hydrates, barium sulfate, and the silicates have been studied at temperatures up to 300°C using a highly reproducible seeded growth technique. The kinetic studies were made in the presence of potential scale inhibitors and the influence of trace heavy metal ions on precipitation was considered.

(16) Calorimetry of Geothermal Fluids and Related Materials

Arizona State University

The objective of this project was to modify and apply an existing high-temperature, high-pressure calorimeter to measurements of enthalpies of dilution in concentrated NaCl-H₂O solutions, and enthalpies of mixing, solution, and precipitation of solid phases in the systems NaCl - CaCl₂ - CaSO₄ - H₂O and NaCl - CaCl₂ - CaCO₃ - H₂O.

(17) Geochemistry of Geothermal Systems

Pennsylvania State University

The objective was to collect geochemical data and model chemical systems for improving process engineering of geothermal plants.

Current Projects

(1) Injection Well Stimulation Chemistry

Vetter Research

The objective of this project is to identify chemical procedures and chemicals that remove or reduce scaling in injection wells. The goal of the research is to significantly extend the life of injection wells by developing appropriate maintenance procedures for periodic well

stimulation. Novel chemical and physical characterization techniques will be used to determine particulates entering geothermal wells. Chemicals, chemical procedures, and rock/chemical interactions will be laboratory tested under simulated near-wellbore reservoir conditions.

(2) Geochemistry Modeling and Fluid Chemistry

Los Alamos Scientific Laboratory

The objective of this contract is to assist DGE in the planning and coordination of national efforts in certain areas of geothermal fluid chemistry and computer modeling of scaling in geothermal energy extraction systems. The contract includes the preparation of requisite codes and comparison of prediction with experimental data to identify additional areas where unit operations can be cost-effectively improved.

(3) Geothermal Brine Modeling

University of California, La Jolla

The objective is to develop an activity coefficient model for geothermal fluids and determine the single electrolyte parameters for binary aqueous solutions of NaOH, KOH, $Mg(OH)_2$, and $Ca(OH)_2$.

(4) Hydrodynamic/Kinetic Reactions and Morphology Changes of Scale-Forming Materials

University of Delaware

This experimental investigation will examine hydrodynamic effects on scale formation kinetics and morphology with scales produced in the laboratory at atmospheric pressure, low shear stresses, and at temperatures from 26-100°C.

Milestones

The major milestones shown in Figure 9 are proposed as a guide for orderly and effective development of private sector R&D as outlined in this report.

FIGURE 9

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MAJOR FLUID HANDLING MILESTONES

FIGURE 9

MAJOR FLUID HANDLING MILESTONES
(Continued)

D. Technology Transfer

Technology transfer is an activity built into the major technical and economic projects in the Geochemical Engineering Program. However, there are needs for special activities intended to disseminate information relating to problem identification, technology and procedure assessments, and other evaluative processes. These functions are most often conducted through conferences and workshops. This section lists the more important information/technology transfer projects.

Completed Projects

- (1) Fluid Management Workshop, 1977
- (2) Mineral Recovery - Fluid Management Coordination Meetings, 1976-77
- (3) Workshop on Scale Control in Geothermal Energy Extraction Systems
Los Alamos Scientific Laboratory
Conference Proceedings LA-7664-C
- (4) International Symposium on Oil Field and Geothermal Chemistry,
Society of Petroleum Engineers, June 1977
- (5) Workshop on Scale Control in Geothermal Systems, 1980
- (6) International Information Exchange: U.S./Italy/Mexico/Iceland
- (7) Sampling and Analysis Methods Handbook
Battelle Pacific Northwest Laboratories

Current Projects

- (1) National Society Workshops
- (2) International Information Exchange: U.S./Italy/Mexico/Iceland

Milestones

The major milestones shown in Figure 10 are proposed as a guide for orderly and effective development of private sector R&D as outlined in this report.

FIGURE 10

MAJOR TECHNOLOGY TRANSFER MILESTONES*

ACTIVITY									
TECHNOLOGY TRANSFER									
TASK	CY 1980			CY 1981			CY 1982		
	FY 1980			FY 1981			FY 1982		
Geochemical Engineering Handbook									
Scale Control and Fluid Management Workshops									
NACE International Symposium									
Newsletter									

* Manuals and handbooks that are project-specific are listed in the milestone charts for the other three program elements.

E. ACCOMPLISHMENTS

The following list highlights significant accomplishments of work sponsored by DGE in the field of geochemical engineering. It is not intended to be an exhaustive list, but rather to indicate the range of achievements recorded to date.

- Battelle Pacific Northwest Laboratories has published a sampling and analysis methods handbook for geothermal fluids which can be consulted by site operators for information regarding appropriate sampling locations in the plant, optimum sampling techniques, what fluid characteristics need to be analyzed, and standardized analytical procedures. The handbook was based upon input from industrial, university, and national laboratories.
- Lawrence Berkeley Laboratory compiled an inventory in 1978 of available geothermal fluid data as an aid to identification of fluid chemistry problems. These data are stored in a computerized information retrieval database.
- In 1978-79, Battelle Pacific Northwest Laboratories selectively assisted the Oregon Institute of Technology and four private developers who were involved in developing geothermal resources for non-electric applications by explaining and demonstrating the "how's and why's" of fluid characterization. This small program was of direct benefit to the participants, and a report of these efforts is available.
- The National Materials Advisory Board of the National Academy of Sciences published a report in 1978 describing the important physical and chemical properties of geothermal fluids and the instrumentation needed for in-line monitoring of these fluid characteristics. This report was valuable for identifying chemistry-related problems and in-line monitoring and control technology requirements.
- Battelle Pacific Northwest Laboratories has been conducting a geochemical case study of Magma's 10 MWe pilot plant at the East Mesa geothermal resource under which fluid analyses are carried out and in-line plant and downhole monitoring instruments are installed and operated. A practical demonstration of the benefits of geothermal-specific monitoring techniques can be found at the Magma facility where a prototype corrosion probe installed under Battelle's instrumentation development program alerted operating personnel to excessive corrosion in the condensing system. The problem was traced to a sulfuric acid injection pump which had not shut down and which could have caused a very costly condenser failure if not

rectified. Other successfully field-tested prototype instruments are a probe to measure steam/brine fractions in two-phase flow during separation, a measurement not previously feasible with other techniques, and a conductivity meter to be used in water quality control, for which a license application has been received from a commercial firm. The conductivity meter has been used to detect efficiency-reducing flashing in heat exchangers, which led to a change in procedures for the shut down/start up cycle of pumps.

- Various DGE-funded studies of scale-forming minerals and testing of potential scale inhibitors for geothermal systems has identified a number of prospective inhibitors for silica scale and one very effective inhibitor for calcium carbonate.
- A large body of data relating to geothermal fluid properties and scaling has been gathered and a number of geochemical models have been developed or improved that will enable optimization of unit operations and greater overall system efficiencies.
- A cavitation descaling technique developed by Daedalean Associates has been successfully field-tested in the severe scaling environment at Niland. This method is less time-consuming than existing geothermal scale control technology. A small test with polymer concrete pipe indicates that this may also be a viable option for this material.
- Aerojet Energy Conversion Company has designed and constructed a mobile geothermal fluid test unit for use in the Imperial Valley geothermal area. This facility will permit the collection of geochemical and scaling data under realistic site-specific conditions to improve energy conversion system design and operation.
- Several new techniques were developed by Lawrence Livermore Laboratory for the measurement of the chemical parameters of the geothermal brines of the Salton Sea geothermal field. These include an insertable probe for acquisition of geothermal fluid samples, an anaerobic incubation and analytical technique for following the rates of silica precipitation at 90°C, and the application of laser particle counting techniques to the characterization of geothermal brines. Related developments are techniques for brine injection testing and electrochemical corrosion rate measurement.
- Lawrence Livermore Laboratory developed an injection treatment process for Salton Sea geothermal brine based on coagulant-assisted solids contact clarification. A pilot-size reactor clarifier was tested with brine effluents from the Geothermal Loop Experimental Facility (GLEF), with the injectability of the treated effluents being acceptable.
- The National Materials Advisory Board of the National Academy of Sciences has published a report entitled "Materials Needs for the Utilization of Geothermal Energy." This report provides an overview of the major materials problems and needs related to geothermal energy systems and recommends actions aimed at addressing the identified materials-related problems. (Report No. NMAB-375).

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