MASTER

**Recommendations for a
U.S. Geothermal Research Plan**

Volume I

Battelle

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RECOMMENDATIONS FOR A U.S. GEOTHERMAL RESEARCH PLAN

VOLUME I

TO

RESEARCH APPLIED TO NATIONAL NEEDS PROGRAM

OF

NATIONAL SCIENCE FOUNDATION

CONTRACT NSF-C839

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DECEMBER 1975

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the help of many persons both in Battelle-Northwest and in other organizations.

We particularly thank Drs. Russell Duff and Dave Riney of Systems Science and Software for their suggestions on fracturing and seismic-subsidence studies; Prof. Henry Ramey of Stanford University for input to the reservoir modeling studies; Robert Greider, Chevron Oil Company, for information on drilling, economics and resource potential; Richard Fulcher, Bureau of Reclamation, Boulder City, Nevada for information on Imperial Valley drilling and exploration; Dr. Meir Carasso of Bechtel Corporation for information on resource estimates; Prof. Gunnar Bodvarsson, Oregon State University, Prof. James Combs, University of California-Riverside, Dr. Pat Muffler, United States Geological Survey, Menlo Park, and Dr. Edward Buffington, U.S. Naval Reserve Center, San Diego, all for information on exploration, assessment and drilling technology; Dr. Mort Smith of Los Alamos Scientific Laboratory for information on the Valles Caldera project; Dr. Oscar Krikorian, Lawrence Radiation Laboratory for corrosion and scaling data; Dave Tillson of Washington Public Power Supply System for contributions to the exploration planning; and Profs. Thomas Crocker of the University of California-Riverside and Sho Sata of the University of California-Berkeley for suggestions on institutional research projects.

Many of the Battelle-Northwest staff made important contributions to this study. Jim Sheff, Duane Deonigi and Bill Reardon contributed to systems analysis; Roger Engel assisted with the programming; Bob Dillon provided many valuable suggestions on thermochemistry research; Ron Walter and Frank Zaloudek made suggestions on thermodynamic and mechanical projects; Pete Owzarski performed thermodynamic calculations; Bill Templeton gave helpful input to the environmental planning; Hal Fullam and Steve Phillips furnished suggestions on geochemical research; and Priscilla Cannon and Judy Harris assisted in the editing.

CONTENTS

	<u>Page</u>
ACKNOWLEDGEMENTS	i
LIST OF FIGURES	v
LIST OF MAJOR TABLES	vii
I. SUMMARY	1
II. INTRODUCTION	5
Planning Period	5
Planning Constraints	6
Program Elements	6
III. SYSTEMS ANALYSIS (by J.B. Burnham)	9
A. Allocation of Research Funds	9
Benefit/Cost	13
Technological Limitations	15
Economic Factors	17
Research Funds Available	18
Historic Growth Patterns	18
Value of Power	25
B. Oil Equivalents	28
C. Impact on Foreign Trade Balance	28
IV. <u>SUBPROGRAMS</u>	32
A. Hot Water (by C.A. Rohrmann)	40
Location	40
Value of Resource	40
State-of-the-Art	41
Problems	42
Development Strategy	42
Projects	43
Schedules and Milestones	55

CONTENTS (continued)

	<u>Page</u>
B. Warm Water (by C.A. Rohrmann)	64
Location	64
Value of Resource	64
State-of-the-Art	65
Problems	65
Development Strategy	66
Projects	66
Schedules and Milestones	66
C. Hot Dry Rock Resource (by P.D. Cohn)	75
Location	75
Value of Resource	78
State-of-the-Art	79
Problems	80
Development Strategy	82
Projects	84
Budget Summary	101
Schedules and Milestones	101
D. Brine (by P.L. Peterson)	115
Location	116
Value of Resource	117
Problems	118
Development Strategy	120
Projects	122
Scheduling and Milestones	140
E. Geopressured Resources (by C.H. Bloomster)	154
Location	154
Value of Resource	154
State-of-the-Art	155
Problems	155
Development Strategy	156
Projects	158
Proof-of-Concept Experiments and Significant Milestones	168

CONTENTS (continued)

	<u>Page</u>
F. Dry Steam (by C.H. Bloomster)	178
Location	178
Value of Resource	178
State-of-the-Art	178
Problems	179
Development Strategy	180
Projects	181
Proof-of-Concept Experiment and Significant Milestones . .	187
G. Exploration (by J.R. Eliason)	192
Objectives	192
State-of-the-Art	192
Discussion of Plans	194
Projects	196
H. Assessment (by G.A. Sandness)	201
Projects	202
I. Drilling (by R.W. Wallace)	209
Objectives	209
State-of-the-Art	209
Discussion of Plans	215
Projects	216
J. Environmental-Social (by J.B. Burnham)	219
Problems	219
Development Strategy	221
Projects	221
K. Institutional Studies (by D.H. Stewart)	224
Institutional Problems	224

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
1	Logic Flow for Development of Recommended Program Plans . . .	9
2	Growth Pattern of the Nuclear Industry	19
3	Growth of Geothermal Installed Capacity	21
4	Installed Geothermal Capacity as a Function of Research Budget	24
5	Oil Equivalent Savings from Geothermal Generation	29
6	Effect of Geothermal Generation on Foreign Trade Balance . .	30
7	Hot Water Geothermal Power (Above 180°C)-A Budget	60
8	Hot Water Geothermal Power (Above 180°C)-B Budget	61
9	Hot Water Geothermal Power (Above 180°C)-C Budget	62
10	Warm Water Geothermal Power (Below 180°C)-A Budget	72
11	Warm Water Geothermal Power (Below 180°C)-B Budget	73
12	Warm Water Geothermal Power (Below 180°C)-C Budget	74
13	Granitic Rocks of Mesozoic and Cenozoic Age in the Western United States	77
14	Hot Dry Rock Geothermal Power-A Budget	110
15	Hot Dry Rock Geothermal Power-B Budget	111
16	Hot Dry Rock Geothermal Power-C Budget	113
17	Hot Brine Geothermal Power-A Budget	149
18	Hot Brine Geothermal Power-B Budget	150
19	Hot Brine Geothermal Power-C Budget	152
20	Geopressure Geothermal Power-A Budget	175
21	Geopressure Geothermal Power-B Budget	176
22	Geopressure Geothermal Power-C Budget	177

LIST OF FIGURES (continued)

<u>Figure No.</u>		<u>Page</u>
23	Dry Steam Geothermal Power-A Budget	189
24	Dry Steam Geothermal Power-B Budget	190
25	Dry Steam Geothermal Power-C Budget	191

LIST OF MAJOR TABLES

<u>Table No.</u>		<u>Page</u>
1	Delphi Weighting of Objectives	11
2	Figures of Merit for Allocation Decisions	12
3	Summary of Forecasted Geothermal Capacity (All Geothermal Resources)	14
4	Capacity Requirements for Western U.S.	22
5	Benefit/Cost Analysis of Geothermal Research (Interest Rate 10%) at 25% Growth Rate	26
6	Benefit/Cost Analysis of Geothermal Research (Interest Rate 10%) of Alternate Growth Rates	27
7	Summary of Economic Calculations at 25% Annual Growth (\$500 million budget)	31
8	Summary of A Budget	34
9	Summary of B Budget	35
10	Summary of C Budget	36
28	Summary of Recommended Budgets for Hot Water Resource Five- (and Ten-) Year Budgets (in \$ millions)	57
30	Summary of Recommended Budgets for Warm Water Resource Five- (and Ten-) Year Budgets (in \$ millions)	69
49	Summary of Recommended Project and Task Budgets for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)	102
68	Summary of Recommended Budgets for Brine Resource Subprogram Five- (and Ten-) Year Budgets (in \$ millions)	143
87	Summary of Recommended Budgets for Geopressed Resources Five (and Ten-) Year Budgets (in \$ millions)	171
98	Summary of Recommended Budgets for Dry Steam Resource Five- (and Ten-) Year Budgets (in \$ millions)	188

LIST OF MAJOR TABLES (continued)

<u>Table No.</u>		<u>Page</u>
103	Summary of Recommended Budgets for Exploration Five- (and Ten-) Year Budgets (in \$ millions)	200
110	Summary of Recommended Budgets for Assessment Five- (and Ten-) Year Budgets (in \$ millions)	208
114	Summary of Recommended Budgets for Drilling Five- (and Ten-) Year Budgets (in \$ millions)	218
118	Summary of Recommended Budgets for Environmental-Social Subprogram Five- (and Ten-) Year Budgets (in \$ millions) . . .	223
119	Summary of Recommended Project Budgets for Institutional Studies Five- (and Ten-) Year Budgets (in \$ millions) . . .	226

RECOMMENDATIONS FOR A U.S. GEOTHERMAL RESEARCH PLAN

I. SUMMARY

Based on data in recent reports⁽¹⁾ and plans for the development of U.S. geothermal resources, a multidisciplinary Battelle-Northwest study team developed a comprehensive research program. Five- and ten-year program plans in this study emphasize critical five-year milestones. Recommended plans are presented here under constraint of three different five-year budgets: \$100, \$300 and \$500 million respectively. Plans are detailed in six resource subprograms: high temperature water, moderate temperature water, hot dry rock, brine, geopressured, and dry steam. Also presented are plans for five subprograms common to all geothermal resources: exploration, assessment, drilling technology, environmental-social, and institutional.

A benefit/cost analysis performed in the Battelle-Northwest (BNW) study shows favorable ratios under all conditions considered; they ranged from 46/1 to 28/1 for the three budget levels at a discount rate of 10 percent. Lower discount rates increase these ratios while higher than 10 percent rates decrease them. The net return (benefit minus cost) analyses

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- (1) - Walter J. Hickel, Geothermal Energy, A National Proposal for Geothermal Resources Research. Final report of the Geothermal Resources Research Conference, Seattle, Washington. Sponsored by the National Science Foundation, Research Applied to National Needs, University of Alaska, September 18-20, 1972.
- Dallas S. Peck, Assessment of Geothermal Energy Resources. September 1972.
 - John L. Colp and Augustine S. Furumoto, The Utilization of Volcano Energy. Proceedings of conference at Hilo Hawaii cosponsored by the National Science Foundation and the Japan Society for the Promotion of Science, University of Hawaii, February 4-8, 1974.
 - California Institute of Technology, Proceedings: Conference on Research for Development of Geothermal Energy Resources. Sponsored by the National Science Foundation, Research Applied to National Needs, September 23-25, 1974, Pasadena, California.
 - California Institute of Technology, Status Report, Geothermal Program Definition Project, Part 1: Program Plan Development. April 4, 1975.

show that the high budget has a return of over \$10 billion; the medium and low budgets show lesser returns. Oil equivalents up to 6.6 million barrels per day are found for the high budget by the year 2000 with somewhat less oil savings for the other budget levels. The corresponding impact on the balance of foreign trade for the high budget is \$19 billion per year in the year 2000 at an oil price of \$8 per barrel. On the basis of these analyses the \$500 million budget is recommended by the Battelle-Northwest study team.

A rationale is described for the allocation of research funds based on the maximum probability of successful economic demonstration in five years and on the energy potential of the resource.

Subprogram plans were first developed using three (high, medium and low) budget definitions. Under these circumstances they represent a cohesive plan for the resource development with little reduction on the research funds. Overlaps between subprograms were then minimized. A comprehensive program plan was finally developed for three specific levels of five-year budget: \$100, \$300 and \$500 million. The specific program plans were recommended on the basis of a probability-payoff model. The derived plans under the three arbitrary budget constraints are summarized below.

A BUDGET (\$100 MILLION)

Recommended expenditures by the Federal government under the A Budget (\$100 million for five years) emphasize (40% of the total) the hydrothermal systems. Dry rock projects total about 17% of the budget. Recommended exploration, assessment, and drilling projects represent about 27% of the budget.

Under the A Budget (\$100 million) an emphasis on early success causes severe restrictions in long term subprograms. Funding is allotted to the high temperature water ($>180^{\circ}\text{C}$) subprogram because it is not likely to encounter delays in exploration or reservoir development. Likewise, enough funding is given to the moderate temperature water ($<180^{\circ}\text{C}$) subprogram for a pilot plant. Under A Budget minimal funding is allocated to other research subprograms. The hot rock subprogram is funded only at a level sufficient

to develop circulating loops at two sites; much of the essential supporting research and development is postponed or eliminated. The brine subprogram is funded only to the extent that essential assessment and thermochemistry, i.e., corrosion, deposition and descaling, work begins. The geopressured resource is funded primarily in reservoir assessment and development projects. Other subprograms are delayed or limited because of the low probability of early success. No significant funding is allocated to the dry steam resource. The subprograms for exploration, assessment and drilling technology are restricted to the minimum necessary to support the proof-of-concept experiments (POCE's). The environmental-social research subprogram is funded at a level which provides only the support needed to write the environmental impact statements for POCE's. Institutional studies are fundamental to the development of all resources and therefore are fully funded in A Budget.

B BUDGET (\$300 MILLION)

The recommended budget for hydrothermal resources is 29% of the total B Budget (\$300 million). The recommended brine subprogram is about 10% and the dry rock subprogram is about 23% of the total. Although this latter subprogram has a long lead time for development, its large energy potential warrants an expanded share of the B Budget. About 30% of the B Budget is allocated to exploration, assessment, and drilling technology projects.

The B Budget (\$300 million) is large enough to fund significant work in the hot brine, dry rock, and geopressured resources. As in the A Budget, major emphasis is placed on hydrothermal resources since they have such a high potential for early successful POCE's. The hot brine subprogram provides for a pilot plant to be constructed in the first five-year period. Construction will be started on a hot rock pilot plant. The geopressured subprogram is funded for production test of a reservoir, conversion equipment design and test, and pilot plant design initiation. Dry steam is funded at a low level with emphasis placed on reservoir stimulation and environmental studies, since this resource activity is being developed by industry and has relatively few unresolved technological problems.

Research subprograms support regional and national exploration and assessment surveys. Likewise, some innovative drilling research should be funded in the first five-year period under B Budget. This budget provides enough funds to start work on these subprograms even though their payoff is beyond the first five years. The environmental-social subprogram provides fundamental data needed to assess the nontechnical impacts of geothermal energy.

C BUDGET (\$500 MILLION)

About 30% of the C Budget (\$500 million) should be allocated to the high temperature water systems, 8% to the hot brine subprogram, and 20% to the dry rock resource. Recommended projects under the geopressed systems subprogram amount to about 4% of the total; the dry steam projects account for less than 1%. About 35% can be allocated to exploration, assessment, and drilling subprograms.

The C Budget (\$500 million) provides for early work on the two pilot plants in each of the hydrothermal system subprograms as well as one each in the brine and dry rock subprograms. The supporting research programs have been expanded considerably over B Budget levels. Supporting exploration, assessment and drilling technology subprograms are large under C Budget and are considered by the Battelle-Northwest study team to be essential to achieving a rapid increase in utilization of geothermal energy.

II. INTRODUCTION

In the past few years a number of plans for geothermal research have been prepared (see footnote in Summary). The two plans most widely distributed were the Hickel report and its predecessor, the Peck report. Both of these served very useful purposes in highlighting the need for geothermal research and pointing out the general areas requiring attention. These and other plans were developed without budget constraints and reflect no systematic analysis of priorities.

Battelle-Northwest was funded by the Research Applied to National Needs (RANN) Program of the National Science Foundation to develop detailed program plans which would build on the experience of these earlier plans. The planning study reported here was initiated late in CY 1973 and updated 18 months later to reflect more recent developments. The recommended plans are designed to maximize the probability of achieving research objectives defined in Section III of this report.

This volume (Volume I) details the techniques used to develop the research plans. The programs and subprograms are described for each type of geothermal resource, as are recommended program budgets and time schedules. An appendix to this volume (under separate cover) includes a glossary of terms and a detailed breakdown of the programs by project and subproject.

Volume II is an executive summary of the study, while Volume III is a utilization plan for the program.

PLANNING PERIOD

A five-year budget with attendant goals has many merits. The period is sufficiently long to allow significant measurable progress. It is short enough so that goals appear within reach. Planning on a five-year cycle is satisfactory for a technology which is partially developed and needs relatively few experiments to bring it to fruition. But a five-year period

may have drawbacks. A major new technology requires a longer period to successfully carry new systems through the various steps of invention, testing component development, and assembly.

Even though the operational budget period is five years for detailed plans, these are extended to ten years to study long range programmatic commitments. Each subprogram is structured for completion within a five-year period where possible, but insuring a maximum probability of success some time within the ten-year period.

PLANNING CONSTRAINTS

Three budgets, \$100, \$300, and \$500 million respectively, are considered. These budgets represent the total five-year Federal expenditure for geothermal research of all types. Ten-year budgets are also included. The ten-year budget was developed for each subprogram on the basis of the total amount of research needed to realize maximum development of the resource under the constraints of high, medium, and low budgets in the first five years. The funding noted for the second five years is merely the difference between the ten-year total and the portion of the subprogram selected for funding under the first five-year budget constraints.

PROGRAM ELEMENTS

The research plan was divided into program elements which consisted of the six resource types and generic (common) elements such as exploration and assessment. The descriptions of these elements follow.

Exploration and assessment are of particular concern in geothermal energy, for one of the greatest present drawbacks to its utilization is a lack of knowledge of its location, nature, and magnitude. For the purposes of this planning study, exploration is defined as: "The development of new techniques, the improvement of present methods, the testing and correlation of these methods in known geothermal anomalies, and their use to discover new geothermal fields." Assessment is defined as: "The determination on a national, regional, and local basis of the physical size and energy potential of existing and newly discovered geothermal fields." There is a degree of

overlap between the two subprograms since exploration tools will also be used for assessment work. Likewise, test holes drilled to prove out surface exploration work may also be used for assessment.

Appendix A is a glossary of terms used in the study. This appendix and the task sheets (Appendix B) are bound separately.

The Hickel report was used as a guide in developing the plan. The study's analysis of research requirements reveals that a more detailed breakdown of geothermal resources is required than is used in the Hickel report. The classification of the resources selected for this study is:

- Hot water - above 180°C (often designated "high temperature")
- Warm water - 150°C to 180°C (often designated "moderate temperature")
- Steam - saturated or superheated
- Brine - water of greater than 3% total dissolved solids
- Dry, hot rock (includes molten magma)
- Geopressured systems - hot water at greater than hydrostatic pressure

Although the hot, dry rock geothermal resource includes molten magma by definition, there are no recommended projects devoted to magma research. All the research devoted to the hot, dry rock will eventually apply to the direct recovery of energy from magma. The additional technical and environmental problems inherent in magma systems, though, make particular magma research projects hard to justify under the program objectives and 5-10 year time frame of this plan.

Battelle-Northwest scientists adopted the programmatic structure of the Hickel report early in the study. As the tasks of cross comparison between subprograms and deletion of redundant elements was performed, it became obvious that a more detailed classification would be required. The six research categories used in the Hickel report are too broad for definition of plans in terms of research projects. A 17-element system was devised; this was large enough to afford the necessary definition, yet small enough for analysis.

As the study progressed, it became clear that the original plan of assigning all costs to the various resources was not sound. For example,

research on exploration techniques should be a general subprogram since it will apply to all resources. Assessment, institutional, and environmental-social research are also generic to resources of every type. The development of new drilling methods also falls in this category of program elements.

Implementation of a long range program plan must be managed with a certain flexibility. There will be many highly inventive and very worthwhile proposals from scientists throughout the ranks of industry, academe and government. However, it was possible to include only a few such proposals that happen to be known to Battelle-Northwest. Specific proposals, as they become available, should be weighed in the same way that the projects and tasks have been in this study. Just as it will be necessary to review plans in the light of on-going experimental results, so they should be reviewed as new unsolicited proposals are received. If a proposal promises a higher probability of achieving the program objectives than a planned project, the new approach should be substituted. In some cases parallel efforts are justified.

The section that follows describes the analytical methods used to select the recommended projects and tasks. The results of the benefit/cost analysis are also detailed. Each subprogram is described; the budget details by project and by task are given. These include a description of critical path items, milestones, and time schedules.

III. SYSTEMS ANALYSIS

This section describes the systems analysis which was performed to design the research programs, to select the program elements within the budget constraints, to determine the cost effectiveness of candidate research budgets, and to arrive at a recommended funding level. Figure 1 is a diagram illustrating the logic flow for the development of these plans.

FIGURE 1. Logic Flow for Development of Recommended Program Plans

Details of the methods used to define the program elements and design the subprograms are described in Section IV. The method of selection of projects for funding under budget constraint is discussed in the following paragraphs.

A. ALLOCATION OF RESEARCH FUNDS

An initial study approach in determining the allocation of funds was to construct an integer linear programming model which would evaluate each

project on the basis of its ability to satisfy NSF objectives, its probability of success, and the quantity and quality of the type of geothermal resource.

With this in mind a miniature Delphi survey was taken of three NSF program officials to determine their evaluation of objectives. The three officials were asked to rate the relative value of the five objectives (see Table 1) by allocating a total of 100 points. The process was iterated once. Table 1 lists the results of this survey. Projects were initially to be evaluated by a computerized resource allocation model. All of the projects and their tasks were given alpha-numeric designations suitable for easy computer programming.

The linear programming approach was dropped. It was found that the data available for the research selection process were so scant that computerization would have been a form of technical overkill. A simple method was devised, though, which converted the values (in meeting the objectives), the objective weighting factors, the estimated size of the resource type, the estimated "quality" (temperature, production cost, etc.) of the resource type, and the probability of project success into budget allocation shares.

In application of this technique it was found that individual projects could be analyzed rather concisely. When a series of projects leading to a successful proof-of-concept-experiment (POCE) was compared to another series, the technique was less definitive. A POCE is defined as the final step in a project which demonstrates the development of a technique, operation of a piece of equipment, or, ultimately, generation of power from a demonstration plant. Maximum emphasis was placed on those projects which had a high probability of achieving a POCE within the first five years.

A second allocation process was based on the following system. Each resource type was assigned a 1985 resource value (potential MWe) based on Battelle-Northwest judgment and data received from Bechtel (see a discussion of these data under the paragraph "Benefit/Cost"). An estimate was made of the probability of bringing that resource through a significant POCE within

TABLE 1. Delphi Weighting of Objectives

	<u>Value Analysis</u>				<u>Standard Deviation (Estimated)</u>
	<u>Respondent</u>				
	<u>1</u>	<u>2</u>	<u>3</u>	<u>Mean</u>	
1. To build the base of fundamental knowledge in the geothermal areas of exploration, assessment, reservoir development, energy conversion, economics, and environmental effects.	20	15	35	25	11.8
2. To provide the continuing supply of trained scientists, engineers, technicians and craftsmen for the utilization of geothermal resources.	7.5	10	5	7.5	3.0
3. To provide a factual basis for institutional frameworks necessary to the orderly development of geothermal energy resources.	10	5	15	10	5.9
4. To provide proven systems necessary to critical functions in the extraction and conversion of geothermal energy.	50	50	40	46.7	5.9
5. To expand the total recoverable reserves of geothermal energy resources in the U.S.	7.5	20	5	10.8	8.9
	100	100	100	100	

five years. In order to make sure that the emphasis on near-term results does not distort long range goals, a second figure of merit was derived. It, too, is based on the estimated size of the resource (in 1985), weighted by the probability of achieving economic generation within 10 years. Table 2 shows the derivation of these figures of merit.

TABLE 2. Figures of Merit for Allocation Decisions

	Columns				
	1	2	3	4	5
	Identified ¹ Resource 1985	Success ² Probability	5-Year Figure of Merit (Cols.1x2)	Success ³ Probability	10-Year Figure of Merit (Cols.1x4)
Hot Water	200	0.8	160	0.95	190
Warm Water	700	0.95	665	0.95	665
Brine	100	0.4	40	0.8	80
Hot Rock	1000	0.2	200	0.6	600
Geopressured	6	0.6	4	0.9	6
Steam	1.5	1.0	2	1.0	2

1. Used here as a dimensionless number representing the relative size of the resource.
2. Probability of achieving milestone POCE in five years.
3. Probability of achieving economic generation in ten years.

Necessary funds to conduct crucial supporting research in exploration, assessment, environmental and institutional studies were subtracted from the total budgets (\$100, \$300, or \$500 million). The remainder was allocated according to the figures of merit. Funding the important POCE's was emphasized to insure their completion. The low priority resource types were funded so that critical POCE's could be accomplished if possible and key research would be at least started, if not finished, in the period.

After definition of five-year plans for each of the three budget levels, each plan was analyzed by several methods to determine the most

effective one. The three measures used in the analysis were: (1) benefit/cost (the ratio of the savings in power cost to the federal investment in the program); (2) oil equivalents (equivalent volume of oil which would be required to generate the power from geothermal plants); and (3) the effect on balance of payments assuming that purchases of foreign oil could be reduced by the oil equivalents of geothermal production. These analyses and their results are further described in the following paragraphs.

Benefit/Cost

Fundamental to the analysis of benefit/cost is an estimate of the growth of the geothermal generation industry in response to investment of federal research funds. If this dependence can be established and a value assumed for the power generated, one can calculate the return on the federal research investment and also make some judgments in the level of research justified.

The worth of geothermal resources is uncertain due to a lack of knowledge of their size, nature and availability. Early estimates of the size of the resource vary by five orders of magnitude. Until this uncertainty is reduced, there will be a reluctance by industry to invest the large sums necessary to expand generating capacity at a reasonable rate.

Work conducted by Bechtel Corporation⁽¹⁾ and The Futures Group under NSF sponsorship has provided the best available understanding of this question. Selected data from their work are presented in Table 3.

The "throughput" estimate in Bechtel's 1974 work is derived from the opinions of some 30 experts in the geothermal industry. It is defined as the maximum capacity which could conceivably be installed and supported by geothermal resources in a given year. This estimate is not constrained by any economic considerations. The two conditions imposed are "normal"

(1) M. Carasso, A Technological Assessment of Geothermal Energy Resource Development, Bechtel Corp. August 1975.

TABLE 3. Summary of Forecasted Geothermal Capacity (All Geothermal Resources)

<u>Year</u>	<u>Throughput Range (MWe 1000's)</u>	<u>Throughput Median (MWe 1000's)</u>
1973	-	0.396 (actual)
1985 - Normal	4-24	10
- Crash	10-144	32
2000 - Normal	20-600	180
- Crash	40-3270	770

development, defined as: "Geothermal technology continues to develop on the same basis that it is presently developing, without externally applied stimuli"; and "crash" development defined as: "Geothermal technology develops under the stimulus of a declared national policy backed by massive governmental support, in which cost is virtually no impediment". It should be noted that the estimates presented are those of maximum possible capacity based on the size of the estimated resources.

In converting such estimates to installed capacity there is a natural tendency to use the most optimistic figures and to assume that there will be no technological or economic impediments to the immediate acceptance of this resource by industry and environmentalists. Such an approach may be acceptable in stimulating the early efforts which are needed to attract interest in the potential of the resource, but it should be avoided in preparing an economic analysis as needed here. Factors which are here considered in formulating an estimate of benefits include:

- Technological limitations which will slow growth.
- Economic factors.
- Funds available for research.
- Historic growth patterns.

If all of these factors are included in the analysis, a growth pattern will emerge that can be promoted with confidence by federal research plans. While this will not agree with the forecasts of the entrepreneurs of the

of the industry, it will be a credible basis for analysis by both government and industry. The impact of these factors on growth follows.

Technological Limitations

Technological limitations to the development of the resource are not severe in the long term, for many of the problems are similar to those of other industries. For example, the chemical problems associated with brines and the hot rock systems are not unique to geothermal energy; they should be solved within the first five-year period. Likewise, the necessary reinjection techniques will be developed. The equipment development problems of heat exchangers and generators will almost certainly be solved within the next five years. The fracturing of hot rock and successful extraction of heat from it will eventually be solved. Due to the complexity of these problems there is almost no probability that this technology will be demonstrated in a time frame which would permit any significant commercial installations before 1985. Exploration and assessment techniques will undoubtedly improve with experience, but early discovery work which must precede large-scale installation of power plants will not be easy or cheap.

Improved drilling techniques will, in the long-term, extend the depth and improve the economics of geothermal resources. In the short term, though, such techniques have little chance of making a significant contribution. Available drilling capacity will seriously limit the rate at which the geothermal industry can expand. The present capacity of the oil industry is about 4800 wells per year (average depth 6,000 feet).⁽¹⁾ It is estimated⁽²⁾ that about 100 wells will be drilled by the geothermal industry in 1974. If the number of these wells doubled every two years (a fantastic growth rate in view of the demand for oil drilling), the industry would drill about 3750 wells through 1981. Time consuming steps which follow successful exploration are: reservoir engineering work (flow

(1) M. O'Donnell, Geothermal Kinetics Systems Corporation, personal communication, December 6, 1973.

(2) R. Greider, Standard Oil of California, personal communication, December 19, 1973.

testing of production wells; successful reinjection, etc.); the plant design which must be adjusted to the particular conditions of the field; the necessary regulatory approvals; and finally, plant construction. On the basis of these factors the assumption was made that no plant whose production wells were not completed by the end of 1981 would be on-line in 1985. If, then, the total number of wells drilled by the end of 1981 is 3750, how much capacity would this support? The range of average capacity per production wells is about 3-10 MWe depending on the type of resource. If one assumes an average of 7 MWe, the following calculation obtains:

$$\begin{aligned}
 1000 \text{ MWe} \div 7 \text{ MWe per well} &= 143 \text{ producing wells} \\
 1 \text{ wildcat well per } 4 \text{ producing wells}^{(1)} &= 36 \text{ wildcat wells} \\
 1 \text{ dry well per } 8 \text{ producing wells}^{(1)} &= 16 \text{ dry wells} \\
 1 \text{ reinjection well per } 2 \text{ producing wells} &= 72, \text{ less } 16 \text{ dry wells which can be} \\
 \text{used for reinjection} &= 56 \text{ reinjection wells}
 \end{aligned}$$

$$\text{Total wells/1000 MWe} = 251 \text{ wells}$$

The resulting capacity on-line by 1985 would then be:

$$\frac{3750 \text{ wells}}{251 \text{ wells per } 1000 \text{ MWe}} = 15,000 \text{ MWe}$$

This indicates an upper limit of installed capacity which is independent of other restrictions. Such calculations as these are simplistic inasmuch as they do not include the need for more operating rigs and require the assumption that some oil drilling rigs will convert to geothermal drilling. In the short term, though, these calculations illustrate a definite bound on the development rate.

(1) R. Greider, Standard Oil of California, personal communication, December 19, 1973.

Economic Factors

A pervasive factor which must be recognized in predicting growth patterns is the investment strategy of industry. Until industry can see a reasonably rapid and safe return, it will not invest any significant sums of money. With the proper tax inducements the resource companies will move into the field with significant investments. (This includes buying up the holdings of small entrepreneurs.) Energy intensive industries such as metal refiners may be the next most likely investors. The slowest to invest will probably be the utilities. The utilities are inhibited by law, regulation and corporate policy from any investments of a speculative nature. When successfully demonstrated, the small (100-200 MWe) plants typical of geothermal installations will be particularly attractive to those utilities with a small system capacity. The extended transmission requirements to bring this power into the distribution grids may not be attractive to all utilities. As the economics and reliability of these plants are proven, though, the utilities will inevitably start to invest.

An economic factor which must be recognized is the present commitment pattern of the utility industry. A few years ago a five-year planning cycle for new capacity was not unusual. With the present lead time of 6-10 years for new installations, utilities must make firm plans at least ten years in advance. For example, the Pacific Northwest Utility Conference Committee recently announced⁽¹⁾ firm plans for 7500 MW of base load and 3700 MW of peaking power. This will cover all of the Pacific Northwest demands through 1985. This means that a sale of a geothermal plant of any size would not be considered for addition to the system before 1986 without major change in commitments. Firm contractual commitments will severely deter the rapid entry of a new technology. In the long term this is, of course, not a serious constraint. Once reserves are proven, the geothermal planning cycle may be five years or less (half that of a nuclear plant); this will eventually facilitate rapid entry of geothermal capacity.

(1) Tri-City Herald, December 18, 1973.

Research Funds Available

The limited availability of funds for geothermal research must be recognized. The moon-landing mission was funded 18 years ago at approximately \$2 billion per year. The AEC has spent about \$1 billion per year for the last 20 years on the development of power reactors. Contrasted to these budgets, the range of probable geothermal research budgets is from \$20 to \$100 million per year. While this is a significant effort, it cannot possibly be compared in effectiveness to the billion dollar budgets mentioned above. It must be realized that without a national commitment to the development of this single resource, it will have to compete for priorities on materials and manpower with other concurrent research efforts. Some of these programs may be an order of magnitude larger.

Historic Growth Patterns

The last factor which must be considered in predicting the growth of the geothermal industry is the classical pattern followed by other technologies. There is ample theory for the development of a resource.⁽¹⁾ Likewise, there is an excellent recent example of a new industry whose advent was stimulated by large government research expenditures. Figure 2 illustrates the classical nature of the nuclear industry's growth. It follows a compounding equation of the form:

$$C_n = C_0 (1 + x)^n$$

where C_n = total installed capacity in year n

C_0 = capacity at year 0

x = compounding factor

n = number of years

(1) M.K. Hubbert, "Degree of Advancement of Petroleum Exploration in the United States", J. Am. Assoc. Pet. Geol., Vol. 51, No. 11, pp. 2207-2227.

FIGURE 2. Growth Pattern of the Nuclear Industry

Source: PNL Power Plant Data File (Regional Analysis of the U.S. Electric Power Industry, BNWL-B-415, V. 1, 2)

In the case of the growth of nuclear generation, the annual growth rate has been a steady 39% per year between 1957 and 1979 (projected). (Current utility financing problems and decreased demand have caused cancellation of many plants, particularly affecting capital-intensive nuclear plants.) As with other natural resources, when the most economic reserves have been depleted, competition forces a flattening in the growth rate.

The Battelle-Northwest estimate is that geothermal capacity will most probably grow at a compound rate of 25% per year at least to the year 2000. This prediction is based on the assumption that an active federal research effort will produce successful demonstrations that will stimulate large industrial investments. If a national commitment were made to the development of geothermal energy, it is conceivable that a short-term growth rate of as much as 42% per year could be achieved (25,000 MWe by 1985). If a minimal federal effort is made to stimulate geothermal development, the historical growth rate of 10% per year should result in an installed capacity of about 2000 MWe by 1985. Both of these growth patterns are shown in Figure 3, which illustrates these rates and also those of several other estimators.

Suffice it to comment only on the BNW projection as compared to others shown in Figure 3. The Hickel-Rex growth pattern indicates a compound growth rate of 68% per year in the 1975-1985 period when all the major restrictions blocking entry are in effect. From 1985-2000 a compound rate of 8% per year is indicated. This is a time period in which the hot rock technology should be coming into play. Such a growth pattern is hard to explain. The National Petroleum Council forecast is based on a capacity of 1500 MWe in 1975. If a figure of 750 MWe is used, the NPC curve duplicates the Hickel-Rex one and can be considered in the same light. The plot of the Bechtel data (median normal) is included only for reference inasmuch as it is not intended to be an estimate of actual installed capacity but only that which is technically possible. The Bechtel "crash" model is also included for reference only. The Department of Interior forecast, while exhibiting the classical exponential growth pattern of a new technology, is, in our opinion, lower than should be realized with aggressive

FIGURE 3. Growth of Geothermal Installed Capacity

federal development efforts. As is always the case with prognostications, we must wait a number of years to determine which estimate is the correct one.

An estimate of the upper bound on the growth rate can be obtained from the forecast of demand for the Mountain and Pacific FPC regions as taken from the National Power Survey. Since the FPC estimates (see Table 4) are historically on the high side and include a 20% reserve capacity, they should indicate the maximum demand for new capacity.

TABLE 4. Capacity Requirements for Western United States (MWe) *

<u>Year</u>	<u>Total Capacity Including 20% Reserve</u>	<u>Cumulative Base Load Additions**</u>
1975	95,000	-
1980	136,000	37,000
1985	191,000	86,000
2000	480,000	347,000

*Federal Power Commission, National Power Survey, 1970 (Pacific and Mountain Regions)

**Assuming 90% of new capacity will be base load.

Between 1975 and 1985 about 37,000 MWe new capacity will be added in the regions where the geothermal resource is prevalent; by 1985, 86,000 MWe of new capacity will have been added. The BNW-predicted 7,000 MWe geothermal capacity added by 1985 represents about 8% of the available market. By contrast, nuclear energy captured only about 3% of the available market in its first decade. The predicted installation of 198,000 MWe by the year 2000 represents about 50% of the available Western market. Both of these figures predict a rather optimistic rate of market penetration, although the year 2000 figure is slightly misleading. By that time there will have been a number of base load plants retired from the system.

Geothermal energy would be in the competition for this market. Hence, the 198,000 MWe of predicted geothermal capacity might be only 35-45% of the total capacity needed in the 25-year period.

In order to calculate the benefit/cost relationship of the research investment, it is necessary to make some assumptions about the growth of the industry as a function of the size of the research investment. This is an abstruse question which involves a large judgment factor. There is the possibility that lowering the research level will not change the rate of growth of the industry but will only delay it. There is likewise the chance that the rate of growth will be decreased by a smaller research effort, or both a delay and a decreased rate might result. It was the conclusion of six of the Battelle-Northwest scientists working on this project that the rate of growth would eventually be the same under any of the three research budgets studied. The advent of this accelerated growth would be delayed, though, by lower research expenditures. It is not possible to rigorously defend this assumed growth scenario, but it has a qualitative logic. This logic is based on the consistent assumption that federal research expenditures will act as a stimulus for industrial development. Once economic viability of the various resources has been demonstrated, economic demand will dictate the growth of installed capacity. It is concluded, then, that the decreased research budget will only result in the delay of the demonstration of economic viability.

In a BNW Delphi exercise it was concluded that the reduction of the budget from \$500 to \$300 million would delay the advent of the accelerated growth by two years; reduction from \$300 to \$100 million would cause another 2.5 year delay. This imbalance reflects a judgment on the relative efficiencies of the various research budgets. Stated another way, as the budget increases, certain diseconomies of scale start to set in. Another assumption was made that the early growth of installed capacity would be unaffected by the research efforts. It was further assumed that the short-term growth to about 1450 MWe would be essentially independent of the level of research. Whatever error is involved in this simplifying assumption has a negligible impact on the resulting prediction. Figure 4 illustrates the conclusion.

FIGURE 4. Installed Geothermal Capacity As A Function of Research Budget

Value of Power

The value of power generated from this geothermal capacity is calculated on the basis of displaced oil at \$8 per barrel (one could use values from \$5-\$12 per barrel). When oil at this price is burned in a base load plant at the national average heat rate (about 35%⁽¹⁾ thermal conversion efficiency) fuel costs of around 12.5 mills/kWhr are incurred. Adding capital costs of 9 mills/kWhr,⁽²⁾ this generation would cost around 22 mills/kWhr. Assuming that geothermal power will cost in the range of 10-12 mills/kWhr, a saving of 10 mills/kWhr generated by geothermal can be calculated. One can use several approaches to the analysis of the units of geothermal power. If no oil is available and the economy must forego this electrical energy, the value to the economy is considerably higher. If a free market for oil is reestablished, prices could go down and a considerably lower incremental cost would result.

Since the benefits and costs will be accruing at different times in the future, calculations should take into account the time value of money. Future costs and benefits are discounted and reduced to an equivalent present worth. The R&D costs are assumed to be linear over a five-year period (1975-1979) and the benefits were accrued over the time period 1975-2000. In order to test the sensitivity of the analysis to discount rates, three rates were used--7%, 10% and 18%. These represent a range of rates often used by the federal government (7-10%) and utilities (18%) in the analysis of projects. All costs and benefits were discounted to 1975. Table 5 shows the results of this analysis.

The results are not markedly changed when the analysis is run with 7% and 18% discount rates. As is to be expected, the lower rate yields higher benefit/cost (B/C) ratios and higher net returns (benefit-cost) since more credit is given to the later years in the analysis period. Even

(1) EEI, Historical Statistics of the Electric Utility Industry, 1970.

(2) J.R. Sheff and L. Holmes, Regional Analysis of U.S. Electric Power Industry, Volume 5-Capital Cost Analysis, BNWL-B-415, April 1975.

TABLE 5. Benefit/Cost Analysis of Geothermal Research
(Interest Rate 10%) at 25% Growth Rate

<u>Budget</u>	<u>Benefit/Cost</u>	<u>Benefit-Cost (\$ Billions)</u>	<u>Year B/C Ratio Exceeds Unity</u>
A (\$100 M)	45.8	3.24	1986
B (\$300 M)	28.5	6.26	1985
C (\$500 M)	27.8	10.2	1984

with an 18% discount rate (comparable to that used by industry for analyzing new ventures) the benefit/cost ratios for the A, B and C Budgets are respectively 13.7, 9.0 and 9.0.

Budget Recommendations

In making a choice of the budget to recommend, it is important to consider three factors. The first of these is the benefit/cost ratio. If this is less than unity for any budget, that budget cannot be recommended for acceptance. If the budgets being considered are a large fraction of the total national energy research budget, each budget's benefit/cost ratio must be considered in conjunction with all other competing energy budgets to select the combination that yields the maximum aggregate B/C ratio. This is not the case here as the three trial budgets are each a small fraction of the \$10-\$20 billion energy budget predicted for this time period. All the B/C ratios are large and hence need no further consideration in the selection.

The analysis performed above was made on the basis of the 25% per year compound growth rate. As discussed earlier, the lowest conceivable rate of compound growth is 10% per year while the highest is 42%. Table 6 shows a similar analysis of benefit/cost ratios with these lower and higher growth rates:

TABLE 6. Benefit/Cost Analysis of Geothermal Research
(Interest Rate 10%) at Alternate Growth Rates

<u>Budget</u>	<u>Benefit/Cost For 10% Growth Rate</u>	<u>Benefit/Cost For 42% Growth Rate</u>
A (\$100 M)	4.7	409
B (\$300 M)	2.5	332
C (\$500 M)	2.1	405

It should be noted that the federal research budgets all have a favorable benefit/cost rate even for the very low rate of growth.

The next factor to be considered is the net return (benefit minus cost) from the research investment. All three of the budget programs at 25% annual growth rate have a large return: \$3.2 billion for the A Budget, \$6.2 billion for the B Budget, and \$10.2 billion for the C Budget. The latter is significantly larger than the others and should be recommended.

The last factor which needs examination is the year in which the benefit/cost ratio exceeds unity. The importance of this type of analysis lies in the uncertainty of the time period over which the accuracy of the prediction will hold. As was discussed earlier, any resource reaches a point of maturity at which its initial growth rate decreases in the face of marginal reserves, competition from other sources, etc. The time at which this inflection point is reached can be calculated by a sophisticated analytical technique in which the entire energy economy is modeled. The resource is thrown into the competitive market and the computer calculates its history. Such analysis is beyond the scope of this planning study, but reasonable growth rates have been assumed and have been projected for 25 years. This approach should be checked by examining the year-by-year benefit/cost ratios. If the ratio does not exceed unity until the 20th or 25th year, the program may be suspect because its pay-off is dependent on long term predictions. In this case (25% annual growth rate) the A, B and C Budgets all become winners in relatively short times -- respectively 11, 10 and 9 years after their start. By contrast, the C Budget at a 10% annual growth rate does not exceed a benefit/cost ratio of 1 until the 17th year.

Thus, on the basis of these analyses the C (\$500 million), B (\$300 million) and A (\$100 million) Budgets are recommended in that order.

B. OIL EQUIVALENTS

In this time of severe oil shortages a valid measure of an alternate energy resource is the amount of oil to be saved from its use. Once the growth of the industry has been established, this is an easy conversion. Using the growth pattern forecasts shown in Figure 4 the national savings in oil consumption were calculated. The 1970 average heat rate for oil fired generating plants was used in the calculation -- 9784 Btu/kWhr.⁽¹⁾ It was also assumed that residual oil has a heat value of 6.287 million Btu per barrel. The savings to be realized are shown in Figure 5. As can be seen, this will range from 2.5 to 6.6 million barrels per day by the year 2000. Another energy equivalent is that of coal. Assuming 12,000 Btu/lb coal, another energy factor is that 87 million tons of coal per year are equivalent to one million barrels of oil per day.

C. IMPACT ON FOREIGN TRADE BALANCE

If the oil equivalents discussed above are imported, the effect on the U.S. balance of payments is profound. Evaluating this oil at \$8 per barrel, the annual savings are plotted in Figure 6. By the year 2000 these savings will range from \$7 to \$19 billion dollars per year. It should be noted that the price of oil has fluctuated wildly in the past four years (from \$2.50 to \$15 per barrel). The savings might well be significantly higher than those calculated.

The economic calculations of the previous sections are summarized in Table 7. It should be noted that the 1974 prediction of installed capacity for 1975 was not realized; the actual capacity at the end of 1975 was about 500 MWe.

(1) EEI, Historical Statistics of the Electric Utility Industry, 1970.

FIGURE 5. Oil Equivalent Savings From Geothermal Generation

FIGURE 6. Effect of Geothermal Generation on Foreign Trade Balance

TABLE 7. Summary of Economic Calculations at 25%
Annual Growth (\$500 million budget)

<u>Year</u>	<u>Installed Capacity (1000's MWe)</u>	<u>Oil Equivalent (millions bbls/day)</u>	<u>Impact on Balance of Trade (\$ billions/yr)</u>
1975	0.75	0.025	0.073
1980	2.3	0.077	0.22
1985	7.0	0.23	0.68
1990	21.0	0.71	2.1
1995	65.0	2.2	6.3
2000	199.0	6.6	19.0

IV. SUBPROGRAMS

Although the subprogram descriptions which follow are self-explanatory, some explanation of the organization of geothermal plans is needed. A simple approach is to categorize all the subprograms by resource type. The advantage of such an approach is that the research is focused on an identifiable goal -- the demonstration of the technical and economic viability of this resource. All of the critical path experiments are defined along with the backup approaches deemed necessary to maximize the probability of achieving this goal. The resulting plan is fully integrated and sufficient to the goal.

In the summary of the budgets which will follow, line items, e.g., hot water, brine, etc., were originally derived in such a manner. An expert was given the task of deriving a research plan which would bring his assigned resource to fruition. He consulted other Battelle-Northwest staff, outside consultants, and the literature. He developed independently a comprehensive plan which would have the maximum probability of success. He was to formalize his planning as realistically as possible. Although he was guided by an urgency for five-year completion, he was to achieve this only if a reasonable probability of success could be assured within the budget constraints. In the original planning, no specific budget constraint was imposed on the individual planners although they were told to think in the general context of the total A, B and C Budgets. Lastly, they were to build their plans on a ten-year basis to insure completion of those projects which could not be completed in the five-year period. The advantages of planning the development of a new technology over a ten- rather than five-year period have been discussed in Chapter I of this report.

It is obvious that several major classes of research do not fit into this project-oriented format. Exploration and, to a degree, Assessment efforts cannot be categorized according to individual resources. A significant effort in this area is needed for all types of geothermal

resources. Drilling development is another large project which does not lend itself to allocation by resource. While the Environmental-Social and Institutional efforts are not as large in dollar cost as the above, the cross-cutting characteristic is even more pronounced. Thus, five generic programs are added to the horizontal list of subprograms. This means, then, that not only the resources but the generic subprograms have an integrated plan.

All plans are focused on the major program goal -- the successful proof of the power generating capabilities of geothermal resources. Ancillary benefits of resource development were considered worthwhile by-products. For example, the use of geothermal waters for desalination is of potential major importance, but the incorporation of the plans and budgets for such projects confuses the issue seriously. Likewise, the evaluation of the subprogram which includes a by-product such as water becomes unclear. How much credit should be given for the value of the by-product? In cases where major programs are in place (such as the desalination experiment of the Department of the Interior), those parts of the program which are designed to study power generation are separated as much as possible. The value and cost of those subprograms are analyzed as individual projects. Each subprogram plan for a resource type includes projects in which the value and cost of recovery of by-products are studied.

Since the subprograms were planned independently, there is certain overlap in details. Research on the binary fluid cycle is an example of such overlap. Each resource plan recognizes the potential advantages of this option and provides some funds for its study. This redundancy is pruned from the overall plan. The major research on the binary fluid cycle is funded under the warm water (<180°C) subprogram. Only those features of the cycle unique to other resources are funded by them. Assessment work is another area with a considerable amount of overlap. This is resolved by constraining the assessment work to be done under a resource subprogram to the specific definition of reservoirs needed for pilot plants.

The method by which funds are allocated to the subprograms is described in Chapter III. Summaries of the three budgets are shown in Tables 8, 9 and 10.

TABLE 8. Summary of A Budget
(in \$ millions)

	00 PROGRAM SCOPING & PLANNING	01 EXPLORATION	02 ASSESSMENT	03 RESERVOIR DEV - MODELING	04 RESERVOIR DEV - PROD WELLS	05 RESERVOIR DEV - FRAC & STIM	06 REINJECTION TECH	07 POWER GEN CYCLES	08 THERMOCHEMISTRY	09 EQUIP DESIGN, DEV & TESTING	10 PILOT PLANT DES	11 PILOT PLANT CONST	12 PILOT PLANT OPER	13 SUPPORTING RES	14 ENVIRONMENTAL STUDIES	15 POWER ECON ANAL	16 MULTIPLE USE OF RESOURCE	17 UTILIZATION PROJ	TOTAL
H - HOT WATER > 180°C	.5	1.9	.5	1.5	.4	1.5	.15	.5	7.6	1.0	7.0		5.7	1.45	.35	.6	.45	31.1	
C - WARM WATER < 180°C	.2	.5	.2	.2				.5	1.0	.2	3.3		1.0	1.0	.35		.45	8.9	
P - BRINE	.1	2.0	.1			.6		2.5										5.3	
R - DRY ROCK	.3	2.1	.2		5.0	4.1	.2	2.0	3.1					.2	.1			17.3	
G - GEOPRESSURED	.05	.75		1.0	.05	.1	.1	.15	.95				.2	.4	.05		.2	4.0	
S - DRY STEAM	.02		.19		.05		.02							.10	.02		.1	.5	
X - EXPLORATION	.2	6.0											5.9					12.1	
A - ASSESSMENT	.3	8.4																8.7	
D - DRILLING	.2								6.7									6.9	
E - ENVIRONMENTAL-SOCIAL	.3													3.5				3.8	
I - INSTITUTIONAL																	1.3	1.3	
TOTAL	2.2	6.0	15.7	.99	2.7	5.5	6.3	.5	5.7	19.4	1.2	10.3	12.8	6.7	.9	.6	2.5	100.0	

TABLE 9. Summary of B Budget
(in \$ millions)

	00 PROGRAM SCOPING & PLANNING	01 EXPLORATION	02 ASSESSMENT	03 RESERVOIR DEV - MODELING	04 RESERVOIR DEV - PROD WELLS	05 RESERVOIR DEV - FRAC & STIM	06 REINJECTION TECH	07 POWER GEN CYCLES	08 THERMOCHEMISTRY	09 EQUIP DESIGN, DEV & TESTING	10 PILOT PLANT DES	11 PILOT PLANT CONST	12 PILOT PLANT OPER	13 SUPPORTING RES	14 ENVIRONMENTAL STUDIES	15 POWER ECON ANAL	16 MULTIPLE USE OF RESOURCE	17 UTILIZATION PROJ	TOTAL
H - HOT WATER > 180°C	.5	2.6	.6	2.5	.7	2.0	.2	1.0	9.5	1.5	8.0		7.6	2.1	.5	.8	.7	40.8	
C - WARM WATER < 180°C	.5	2.6	.6	2.5	.7	2.0	.2	1.0	5.3	1.5	9.0		7.6	2.1	.5	.7	.6	37.4	
B - BRINE	.5	3.0	.4	3.0	1.3	3.0	.2	2.5	3.1	.8	6.0		3.0	.5	.2	2.0	.5	30.0	
R - DRY ROCK	.9	15.1	.4		13.9	7.4	1.7	5.8	8.6	1.8	1.8		8.3	.9	.2	1.2	.4	68.4	
G - GEOPRESSURED	.3	2.75	.2	4.0	1.0	1.1	.27	.9	1.45	.73			.4	1.1	.3	.1	.4	15.0	
S - DRY STEAM	.1		.3		1.25	.1	.1	.1						1.0	.3		.75	4.0	
X - EXPLORATION	.2	10.8											20.0					31.0	
A - ASSESSMENT	.4	32.6																33.0	
D - DRILLING	.3								30.8									31.1	
E - ENVIRONMENTAL-SOCIAL	.3												7.7					8.0	
I - INSTITUTIONAL																	1.3	1.3	
TOTAL	4.0	10.8	58.7	2.5	12.0	18.9	15.6	2.7	11.3	58.8	6.3	24.8	46.9	15.4	2.0	4.8	4.7	300.0	

TABLE 10. Summary of C Budget
(in \$ millions)

	00 PROGRAM SCOPING & PLANNING	01 EXPLORATION	02 ASSESSMENT	03 RESERVOIR DEV - MODELING	04 RESERVOIR DEV - PROD WELLS	05 RESERVOIR DEV - FRAC & STIM	06 REINJECTION TECH	07 POWER GEN CYCLES	08 THERMOCHEMISTRY	09 EQUIP DESIGN, DEV & TESTING	10 PILOT PLANT DES	11 PILOT PLANT CONST	12 PILOT PLANT OPER	13 SUPPORTING RES	14 ENVIRONMENTAL STUDIES	15 POWER ECON ANAL	16 MULTIPLE USE OF RESOURCE	17 UTILIZATION PROJ	TOTAL
H - HOT WATER > 180°C	.5	6.3	1.0	4.2	1.2	2.5	.4	2.7	14.0	2.0	11.6	1.0	21.1	5.2	.7	1.5	1.3	77.7	
C - WARM WATER < 180°C	.5	6.8	1.0	6.2	1.2	2.5	.3	2.7	8.7	2.0	12.2	1.0	19.0	5.2	.75	1.5	1.3	72.85	
B - BRINE	.6	4.0	.4	4.0	1.3	4.2	.5	2.5	4.7	.8	6.0		3.0	1.1	.4	2.0	1.1	36.6	
R - DRY ROCK	1.1	16.5	.4		36.9	7.4	1.9	6.3	9.6	3.9	3.8		8.3	1.5	.5	1.5	1.0	100.6	
G - GEOPRESSURED	.4	3.75	.2	4.5	1.0	1.1	.36	1.14	1.9	1.0			.5	1.3	.35	.1	.5	18.1	
S - DRY STEAM	.15		.4		1.25	.1	.1	.1						1.1	.4		.9	4.5	
X - EXPLORATION	.3	25.0											25.0					50.3	
A - ASSESSMENT	.5	74.2																74.7	
D - DRILLING	.4								52.6									53.0	
E - ENVIRONMENTAL-SOCIAL	.3													10.0				10.3	
I - INSTITUTIONAL																	1.3	1.3	
TOTAL	4.8	25.0	112.1	3.4	18.9	42.9	17.8	3.6	15.4	91.5	9.7	33.6	2.0	76.9	25.4	3.1	6.6	7.4	500.0

As seen in the three tables, the total A, B and C Budgets comply with the \$100, \$300 and \$500 million five-year constraints. The horizontal lines (resource subprograms and five generic studies) are discussed in later sections, but a few comments should be made about the vertical totals. Projects 02 and 03 (Exploration and Assessment) total \$21.7 million for all subprograms in the A Budget. While this is over 21% of the total budget, it is still considered by the Battelle-Northwest team to be much too low to move geothermal resource utilization at the desired rate. If these two projects are funded at the level considered barely satisfactory, \$50-\$60 million, the other programs suffer to the point where successful POCE's become highly unlikely. In the B Budget, though, these projects are funded at a level of about \$70 million. With this size of budget allocation the general problem of resource definition can be attacked; whereas in the A Budget most of the effort is restricted to the discovery and assessment of reservoirs for R&D purposes. The C Budget allocates almost \$140 million to these projects. At this level the team believes the major problem of geothermal resource definition (nature, location and size) can be solved.

An important caveat arises at this point. If private industry should pick up this effort at an unexpectedly high rate, the federal effort should be reduced accordingly. The recommended budgets here are based on the assumption that industry will explore at a rapidly increasing rate for dry steam, at a lesser rate for hot water, and at a restricted rate for the other resources.

Projects 03, 04, 05 and 06 are associated with Reservoir Development technology. In the A Budget these efforts are concentrated on solving the specific problems necessary to achieve the desired POCE's. The recommended budget for these efforts goes from \$16 to \$50 to \$93 million in the three budgets. This progression results from the expectation that each new reservoir will have unique problems which must be solved.

The effort in the study of alternate generation cycles (such as alternate binary systems, rotary vane engines, helical screw expanders, etc.) is severely limited in the A Budget, but increases to \$2.7 and \$3.6 million in the B and C Budgets respectively.

Project 08 is denoted by a coined word -- Thermochemistry. This covers the chemical and physical analyses of the resource, its erosivity, its deposition characteristics above and below ground, and its corrosivity. Advanced research on materials and equipment to solve these problems is also included. This is a very important geothermal research project. One could make this a generic effort such as drilling development. Due to the multitude of specific design and operating problems of this nature which would arise at every site, it is allocated to the resources. There is an advantage, though, to concentrating a major portion of this research at one or two centers of excellence. A research laboratory could perform the fundamental property studies and give support to smaller resource-oriented efforts as needed.

The research under Projects 09, 10 and 11 is roughly proportional to the number of plants constructed in the five-year periods. While there is certainly some carryover in equipment design and testing, each new plant will have unique features.

Supporting Research, Project 13, is limited in the A Budget to \$13 million; this is allocated primarily to assistance of the hot water and exploration efforts. It is raised markedly in the B and C Budgets.

There are specific environmental studies, Project 14, which need to be performed in the selection and operation of each POCE site in contrast to the generic studies of environmental-social effects. The budgets reflect the increase in this effort as the number of pilot plants under design increases.

The effort on economic analysis of the power plants, Project 15, grows roughly proportional to the completion rate of the plants; there is only minimal analysis possible until these are constructed and begin to operate.

The utilization program budgets, Project 17, reflect the increasing information to be disseminated. This is roughly proportional to the size and state of completion of the research effort.

A discussion of the line (horizontal) subprograms follows. It should be noted again that the plans were formulated in these subprograms. The vertical project totals previously discussed evolved from the subprogram planning. The major control on the vertical totals was the elimination of serious overlaps.

A. HOT WATER

Although geothermal waters have a wide range of temperatures, Hot Water in this report means those waters of low salinity (less than 3% by weight dissolved solids) and with temperatures above 180°C at the depth of the resource. Such waters generally have appreciable concentrations of dissolved gases such as hydrogen sulfide, carbon dioxide, ammonia and possibly methane. The composition of the salt content can vary widely but is expected to comprise principally sodium (alkali metal) and calcium (alkaline earth metal) chlorides, together with silica. Appreciable concentrations of boron may also be present. Water below 180°C is considered a separate resource since it will not flash, will not self pump, and will have a different thermochemistry. For intelligent planning, it is necessary to correlate as closely as possible the size and nature of the resource with its problems and the cost of the solution.

Location

The prevalence of hot springs throughout much of the Western states and Alaska is indicative of the widespread existence of hot water resources beneath the surface. However, the assessment of such surface occurrences to provide an appraisal of the resource at its depth of origin is very uncertain. Such uncertainties can be resolved only by rather extensive drilling and sampling at depth. Some impressive areas of hot water resources have been inadvertently uncovered in wells drilled for oil or gas. Although salinities can vary greatly over short distances, hot waters of low salinity are prominent in the Salton Sea and Imperial Valley areas of California, with an extension into Mexico near the Colorado River delta. These systems though variable are considered to be large enough to support considerable geothermal power development. In the Mexico area power production has already commenced.

Value of Resource

A realistic assessment of the size of these hot water resources is hard to establish at the present. Some preliminary estimates gathered by

Bechtel⁽¹⁾ indicate the development of liquid-dominated geothermal resources will be as follows:

	<u>1985 Normal</u>	<u>1985 Crash</u>	<u>2000 Normal</u>	<u>2000 Crash</u>
Identified Liquid-Dominated Resources (10 ⁶ Mwt. yrs)	10	1000	50	1000

Battelle-Northwest estimates that of the liquid-dominated resources about 20% will be hot water as defined here. The hot water resource may then be about as shown below:

	<u>1985 Normal</u>	<u>1985 Crash</u>	<u>2000 Normal</u>	<u>2000 Crash</u>
Identified Hot Water Resources (10 ⁶ Mwt. yrs)	2	200	10	200

As pointed out by Bechtel, these numbers are preliminary and subject to change. It should also be noted that a range in the estimates of these resources of from one to two orders of magnitude are reported by Bechtel. The median values are reported here.

State-of-the-Art

Geothermal hot waters are being used for power production in other parts of the world, generally by flashing off the steam at pressure suitable for delivery to a turbine-generator. Such systems are operating in New Zealand and Mexico. In Russia (Siberia) a small power plant has been operated using a binary fluid cycle employing a fluorocarbon. An isobutane cycle has been considered for commercial demonstration in the U.S. The choice of steam flashing or a binary fluid system is determined by the temperature of the water as delivered to the surface.

(1) M. Carasso, A Technological Assessment of Geothermal Energy Resource Development, Bechtel Corp. August 1975.

Problems

Although the whole earth may be considered a potential hot water producer given certain circumstances of rainfall, surface permeability, and confinement, the existence of sites with the necessary conditions limits the resource size. Furthermore, once discovered, there are a number of problems which impair the rapid and productive utilization of such resources.

The principal problems which must be addressed in the utilization of power production based on hot water are the following:

1. The location and size of a reservoir must be established.
2. It must be assured that the field can be operated at suitable productivity for the economic life of the power plant.
3. Thermochemistry-corrosion plus scaling of heat transfer surfaces and other process equipment must be ascertained.
4. Disposal of liquid, solid and gaseous wastes in a way that is acceptable from environmental and economic standpoints must be established.
5. Seismic and subsidence effects may be critical in populated areas and must be evaluated.

Although the proposed research is largely concentrated on the above problems, there are also major projected efforts in the area of engineering and economics.

Development Strategy

The planned research is sufficiently extensive and the recommended support adequate to assure the realization of a significant result within five years. The plans provide for an operating geothermal power plant of 10 to 20 megawatts of electrical output. In order to realize widespread and ultimately large-scale exploitation of the resource, the research program must extend well beyond the critical 5-year period in which the initial productive results can be obtained. Consideration of research support for a full 10-year period has also been estimated. Such extension will provide for more pilot plants to be built in different areas involving

resources of significantly different characteristics: temperature, salinity, producing horizon, etc. With a varied engineering research program it will thus be possible to improve the economics and usefulness of the resource. The budgeting has been further divided to indicate the research funding under low (A), medium (B), and high (C) levels of funding, with attendant shifts of emphasis in the levels of research effort. These results are shown in the project summary Table 10. The main difference between A, B and C funding is that a single and smaller pilot plant is proposed in A, with dependence to a great extent on "present state-of-the-art" equipment and technology. Also, fewer sites are identified and assessed under A. The C Budget supports more extensive research with the objective of gaining major advances in technology and equipment within 10 years so that exploitation can be maximized concurrently with the realization of pertinent data from the pilot plants.

Projects

For most rapid achievement of results in research, a program of parallel investigations or projects is proposed. These projects are further served by a group of tasks. The list of tasks and accompanying descriptions are included in Appendix B, Section H. Since computer tabulations and analysis are anticipated, these projects and tasks are assigned special identifications. The projects related to the research on the Hot Water resource are listed with the letter H followed by a two-digit number. Tasks are numbered with the corresponding project number followed by a two-digit task number, for example, H-02-01, which would be the first task under Project H-02. The budgeting recommended for these projects which comprise the total Hot Water program is shown on Table 10. The various projects are briefly described as follows:

Project H-00 Scoping and Planning

This project supports all the planning, scoping and review work associated with the total research program proposed for the Hot Water resource. Table 11 indicates the recommended funding at the three budgeting levels.

TABLE 10. Summary of Recommended Project Budgets for
Hot Water Resources Five- (and Ten-) Year
Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>31.1 (37.0)</u>	<u>40.8 (56.2)</u>	<u>77.7 (94.5)</u>
H-00 Scoping and Planning	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)
H-02 Assessment	1.9 (1.9)	2.6 (2.6)	6.8 (6.8)
H-03 Modeling	0.5 (0.5)	0.6 (0.6)	1.0 (1.0)
H-04 Production Wells	1.5 (1.5)	2.5 (2.5)	4.2 (4.2)
H-05 Stimulation	0.4 (0.4)	0.7 (0.7)	1.2 (1.2)
H-06 Reinjection	1.5 (1.5)	2.0 (2.0)	2.5 (2.5)
H-07 Power Cycles	0.15 (0.15)	0.2 (0.2)	0.4 (0.4)
H-08 Thermochemistry	0.5 (0.5)	1.0 (1.0)	2.7 (2.7)
H-09 Equipment Research	7.6 (7.6)	9.5 (9.5)	14.0 (14.5)
H-10 Pilot Plant Design	1.0 (1.0)	1.5 (1.5)	2.0 (2.0)
H-11 Pilot Plant Construction	7.0 (7.0)	8.0 (12.0)	11.6 (15.0)
H-12 Pilot Plant Operation	0.0 (2.5)	0.0 (4.0)	1.0 (5.0)
H-13 Supporting Research	5.7 (10.0)	7.6 (15.0)	21.1 (30.0)
H-14 Environmental Studies	1.45 (1.45)	2.1 (2.1)	5.2 (5.2)
H-15 Power Economics	0.35 (0.35)	0.5 (0.5)	0.7 (0.7)
H-16 Multiple Uses	0.6 (0.6)	0.8 (0.8)	1.5 (1.5)
H-17 Utilization Promotion	0.45 (0.45)	0.7 (0.7)	1.3 (1.3)
Total Budget	31.1 (37.0)	40.8 (56.2)	77.7 (94.5)

TABLE 11. Summary of Recommended Budgets for Scoping and Planning Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
H-00 Resource Scoping and Planning	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)

Project H-02 Resource Assessment

This project supports the work required to identify the likely resources and provides for the determination of their detailed qualitative, quantitative and geological features. Budgeting under this project will assure identification of reservoirs of adequate size for the operation of the pilot plant(s) over its design lifetime. For details of the tasks, listed by title below, refer to Appendix B.

TABLE 12. Summary of Recommended Budgets for Resource Assessment Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-02 Resource Assessment</u>	<u>1.9 (1.0)</u>	<u>2.6 (2.6)</u>	<u>6.8 (6.8)</u>
01 - Resource Identification	1.5 (1.5)	1.8 (1.8)	4.0 (4.0)
02 - Resource Evaluation: Quality, Quantity and General Features	0.15 (0.15)	0.3 (0.3)	0.8 (0.8)
03 - Chemical, Physical, Geo- logical and Geothermal Properties	0.25 (0.25)	0.5 (0.5)	2.0 (2.0)

Project H-03 Resource Modeling

This project supports the work needed to assemble all of the data on the resource necessary to define it in terms related to its potential use. The budgeting here provides for funds to "exercise" a generalized model using field data from hot water reservoirs. It is anticipated that unique features of this type resource will require certain modifications of any general model.

TABLE 13. Summary of Recommended Budgets for Resource Modeling Project for Hot Water Resources Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-03 Resource Modeling</u>	<u>0.5 (0.5)</u>	<u>0.6 (0.6)</u>	<u>1.0 (1.0)</u>
01 - Detailed Definition and Description of Resource	0.5 (0.5)	0.6 (0.6)	1.0 (1.0)

Project H-04 Reservoir Investigations - Production Wells

This project supports the investigations which measure the size and productivity of the specific resource and the underground reservoir of water from which the energy is to be recovered. The funding requirements relate directly to the number of reservoirs investigated and the cost of drilling the production-type wells.

TABLE 14. Summary of Recommended Budgets for Reservoir Investigations - Production Wells Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-04 Reservoir Investigations - Production Wells</u>	<u>1.5 (1.5)</u>	<u>2.5 (2.5)</u>	<u>4.2 (4.2)</u>
01 - Drilling of Production Wells	1.2 (1.2)	1.7 (1.7)	3.0 (3.0)
02 - Characterization of Production Wells	0.3 (0.3)	0.8 (0.8)	1.2 (1.2)

Project H-05 Reservoir Investigations - Stimulation

This project is closely related to the previous one. It is concerned with research on methods to improve the flow of hot water from the reservoir. In some wells flow may be adequate, and there is no need for stimulation. However, frequently the very large flows (250,000 lbs/hr) necessary for significant power production will require effective stimulation to be achieved.

TABLE 15. Summary of Recommended Budgets for Reservoir Investigations - Stimulation Project for Hot Water Resources Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-05 Reservoir Investigation - Stimulation</u>	<u>0.4 (0.4)</u>	<u>0.7 (0.7)</u>	<u>1.2 (1.2)</u>
01 - Investigation of Methods and Effectiveness of Flow Stimulation	0.4 (0.4)	0.7 (0.7)	1.2 (1.2)

Project H-06 ReInjection Technology

Since essentially all hot water is expected to be of meteoric origin and also very likely to be discovered in areas which are deficient in rainfall (or snowfall), any such resource may be of limited total volume. Thus a material balance requires production not to exceed precipitation in the hydrologic province unless drawdown is to be experienced. Also, the salinity of the water, if much above potable water quality, will certainly require its disposal by reinjection. This project provides the support for an effective reinjection technology. The development of this technology is dependent on a thorough understanding of the permeability of the geologic structure of the reservoir. Likewise the plugging of the formation by deposition of salts must be inhibited for reliable reinjection systems. The project is designed to provide the geologic and hydrologic data necessary.

TABLE 16. Summary of Recommended Budgets for ReInjection Technology Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-06 ReInjection Technology</u>	<u>1.5 (1.5)</u>	<u>2.0 (2.0)</u>	<u>2.5 (2.5)</u>
01 - Develop Geologic and Hydrologic Data and Mechanisms by Which Effective ReInjection Can be Assured	1.5 (1.5)	2.0 (2.0)	2.5 (2.5)

Project H-07 Power Generation Cycles

This project supports the research needed to enable a logical choice of the power generation cycle to be employed with each resource. The choice will depend on the quality of the resource: its temperature, pressure, salinity and magnitude. For highest temperature waters of low salinity, direct steam flashing would very likely be selected. However, for higher salinities, indirect steam production through heat exchange appears a possible alternative. For lower temperature waters binary cycles employing heat transfer to fluids other than water may be chosen -- such as fluorocarbon (monochlorotrifluoromethane, CuF_3) or a hydrocarbon (isobutane, C_4H_{10}). For such cycles (binary fluid cycles) a wide range of compounds is available with which to match the quality of the heat source.

TABLE 17. Summary of Recommended Budgets for Power Generation Cycle Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-07 Power Generation Cycles</u>			
01 - Determine Most Appropriate and Economic Cycle	0.075(0.075)	0.1 (0.1)	0.2 (0.2)
02 - Selection of Optimum Binary Fluid	0.075(0.075)	0.1 (0.1)	0.2 (0.2)

Project H-08 Thermochemistry

The concern with corrosion of power process equipment in saline waters requires extensive research effort supported by this project. These waters may also contain offensive gases as well as unstable dissolved solids which precipitate under changes in temperature, pressure and concentration. Although there can be great variance in the quality of the waters, solutions to the corrosion, precipitation and scaling problems are expected to have general applicability to all geothermal power activities involving water as the heat transport fluid.

TABLE 18. Summary of Recommended Budgets for Thermochemistry Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-08 Thermochemistry</u>	<u>0.5 (0.5)</u>	<u>1.0 (1.0)</u>	<u>2.7 (2.7)</u>
01 - Investigate Thermochemistry of Hot Water Resource	0.1 (0.1)	0.15 (0.15)	0.6 (0.6)
02 - Study Corrosivity of Typical Materials	0.2 (0.2)	0.5 (0.5)	0.9 (0.9)
03 - Erosivity of Typical Materials	0.1 (0.1)	0.1 (0.1)	0.6 (0.6)
04 - Study Scaling Processes	0.1 (0.1)	0.25 (0.25)	0.6 (0.6)

Project H-09 Equipment Research Testing and Design

This project is an extensive support of engineering research, testing and design of all equipment needed for geothermal power generation, e.g., pumps, heat transfer devices, solids-liquids separators, fluid transport equipment and instrumentation for measurement and control. In addition, the project provides for the large-scale testing of prototype equipment. As with other projects, the results from this work have widespread applicability through the whole field of geothermal power recovery regardless of the type of resource. This project relates to many of the others (particularly H-06, H-07, H-08 and H-10, in that it provides a central testing facility to test materials and equipment.

TABLE 19. Summary of Recommended Budgets for Equipment Research Testing and Design Projects for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-09 Equipment Research, Testing and Design</u>	<u>7.6 (7.6)</u>	<u>9.5 (9.5)</u>	<u>14.0 (14.5)</u>
01 - Pumping Equipment	0.6 (0.6)	0.75 (0.75)	0.75 (0.75)
02 - Heat Transfer Equipment	0.5 (0.5)	0.75 (0.75)	0.75 (0.75)
03 - Solids-Liquids Separators	0.1 (0.1)	0.2 (0.2)	0.5 (0.5)

04 - Fluid Transport Facilities	0.1 (0.1)	0.2 (0.2)	0.5 (0.5)
05 - Instrumentation for Measurement and Control	0.5 (0.5)	0.6 (0.6)	2.0 (2.0)
06 - Construct, Test and Modify Prototype Equipment	5.0 (5.0)	6.0 (6.0)	6.5 (7.0)
07 - Test Operation of Major Cycle Equipment on Nongeo- thermal Hot Water Source (Existing Thermal Power Plant)	0.8 (0.8)	1.0 (1.0)	3.0 (3.0)

Project H-10 Pilot Plant Design

This project provides the design and procurement specifications for the pilot plant(s). The extent of support is determined by the number, size and variety of plants to be provided. The minimum funding is required for a small, single plant employing the simplest "near state-of-the-art" technology. In the B Budget enough funds are available to start the design of a second pilot plant; in C Budget the second plant design is completed.

TABLE 20. Summary of Recommended Budgets for Pilot
Plant Design Project for Hot Water Resources
Five- (and Ten-) Year Budgets

	<u>A. Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-10 Pilot Plant Design</u>	<u>1.0 (1.0)</u>	<u>1.5 (1.5)</u>	<u>2.0 (2.0)</u>
01 - Complete Detailed Design of Pilot Plant(s)	1.0 (1.0)	1.5 (1.5)	2.0 (2.0)

Project H-11 Pilot Plant Construction

This project provides for the complete construction and pre-operational testing of the pilot plant(s). The extent of the project funds is related to the number, size and complexity of the plants to be provided. Typical sites at which such a plant could be installed are Heber, California and Baca Ranch, New Mexico.

TABLE 21. Summary of Recommended Budgets for Pilot Plant Construction Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-11 Pilot Plant Construction</u>	<u>7.0 (7.0)</u>	<u>8.0 (12.0)</u>	<u>11.6 (15.0)</u>
01 - Construction	6.5 (6.5)	7.5 (11.0)	11.0 (13.8)
02 - Pre-operative Testing	0.5 (0.5)	0.5 (1.0)	0.6 (1.2)

Project H-12 Pilot Plant Operation

Pilot plant operation is intended to cover at least three years of on-stream operation. This will take place after the first five years of the program. The cost is a function of the location, number, size and complexity of the plants to be provided. In some cases it may be possible to form a cooperative project with a utility so that transmission lines can be run to the pilot plant and the power sold. It is anticipated that such a highly desirable arrangement would more than cover the cost of operation even on a low plant factor operation (a characteristic of pilot plants). Inasmuch as such a joint venture is always speculative until actually arranged, it seems prudent to budget for pilot plant operation. Budget and time restraints are such that only under the C Budget is it anticipated that these funds will be used in the first five-year period.

TABLE 22. Summary of Recommended Budgets for Pilot Plant Operation Operation Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-12 Pilot Plant Operation</u>	<u>0.0 (2.5)</u>	<u>0.0 (4.0)</u>	<u>1.0 (5.0)</u>
01 - Operation	0.0 (2.5)	0.0 (4.0)	1.0 (5.0)

Project H-13 Supporting Research

This project is an extensive one and supports the very essential work directed toward the maximum and most efficient utilization of the hot water

resource. It is concerned with research on the drilling of large-diameter deep wells and the provision of large-capacity deep-well pumps which can operate at high pressure and high temperature.

It should be realized that for large-scale power production very large flows of geothermal water will be needed -- hundreds of cubic feet per second. Whether this should be recovered from a few large-diameter wells or many smaller ones will be determined by the permeability of the geological structure in which the resource is found and the economics of drilling. However, regardless of this feature most efficient energy utilization requires that the fluid be brought to the surface for flashing or heat exchange as near as possible to the temperature and pressure existing at the source. Considerable research is needed to optimize this multi-parameter problem.

TABLE 23. Summary of Recommended Budgets for Supporting Research Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-13 Supporting Research</u>	<u>5.7 (10.0)</u>	<u>7.6 (15.0)</u>	<u>21.1 (30.0)</u>
01 - Drilling Research for Large-Diameter Holes	3.3 (6.0)	3.6 (7.0)	10.0 (15.0)
02 - Large Deep-Well Pump Research	1.7 (2.5)	2.0 (4.0)	4.0 (5.0)
03 - Drilling	0.5 (1.0)	1.0 (2.0)	4.0 (6.0)
04 - Equipment - Deep Well Pumps	0.2 (0.5)	1.0 (2.0)	3.1 (4.0)

Project H-14 Environmental Studies

This project supports a variety of studies related to environmental matters at each site and with each resource. These studies include: documentation of surveys to comply with regulatory requirements, selection of sites on the basis of local economic, social, political and environmental factors; research on seismicity and subsidence problems at the site and its resource, research on clean-up processes and equipment for waste gases,

liquids and solids, and environmental monitoring and site surveys both before and after plant startup. This work is specific to each individual site. It will be supported by generic environmental research which will address the global environmental-social problems associated with all geothermal resources.

TABLE 24. Summary of Recommended Budgets for
Environmental Studies Project for Hot
Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-14 Environmental Studies</u>	<u>1.45 (1.45)</u>	<u>2.1 (2.1)</u>	<u>5.2 (5.2)</u>
01 - Selection of Specific Resource on the Basis of Economic, Social, Political and Environmental Factors	0.2 (0.2)	0.4 (0.4)	1.0 (1.0)
02 - Compliance with Environ- mental Regulations and Requirements	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
03 - Seismic and Subsidence Investigations and Countermeasures Research	0.5 (0.5)	0.6 (0.6)	1.6 (1.6)
04 - Environmental Monitoring	0.15 (0.15)	0.3 (0.3)	0.5 (0.5)
05 - Site Survey	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
06 - Research on Cleanup Pro- cesses and Equipment for Waste Gases, Liquids and Solids	0.4 (0.4)	0.4 (0.4)	1.5 (1.5)

Project H-15 Power Economics and Analysis

This project supports the work to establish the economics of large-scale exploitation of the specific sites based on the results of earlier tasks. Optimization of the use of the reservoir for large-scale exploitation is also included in this support. This work is also specific to each individual site although techniques may be generally applicable.

TABLE 25. Summary of Recommended Budgets for Power Economics and Analysis Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-15 Power Economics and Analysis</u>	<u>0.35 (0.35)</u>	<u>0.5 (0.5)</u>	<u>0.7 (0.7)</u>
01 - Refine Estimates of Costs for Large-Scale Plants	0.25 (0.25)	0.3 (0.3)	0.4 (0.4)
02 - Optimization of Use of Reservoir	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)

Project H-16 Multiple Use of Resource

This project supports the research involved in assuring the multiple use of the resource, particularly as it relates to mineral values. However, it also covers potentials for the economic use of waste heat and waste water which may be suitable for industrial as well as community use. Research on mineral recovery processes is also included.

TABLE 26. Summary of Recommended Budgets for Multiple Use of Resource Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-16 Multiple Use of Resource</u>	<u>0.6 (0.6)</u>	<u>0.8 (0.8)</u>	<u>1.5 (1.5)</u>
01 - Review and Evaluate Multiple Use Prospects	0.1 (0.1)	0.1 (0.1)	0.25 (0.25)
02 - Assessment of Potential Mineral Values	0.1 (0.1)	0.1 (0.1)	0.25 (0.25)
03 - Research on the Evaluation of Recovery Processes	0.4 (0.4)	0.6 (0.6)	1.0 (1.0)

Project H-17 Utilization Promotion

Successful realization of practical geothermal power from hot water will be a new achievement in the U.S. To promote more general acceptance of the benefits of large-scale applications and to assure an understanding of all of the problems involved, this project supports means of information

exchange and dissemination which will extend application of the technology and research obtained in this program. This will include the organization and conduct of seminars, symposia and conferences; the preparation of professional papers, brochures and educational films; and the preparation of textbooks and handbooks.

TABLE 27. Summary of Recommended Budgets for Utilization Promotion Project for Hot Water Resource Five- (and Ten-) Year Budgets

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-17 Utilization Promotion</u>	<u>0.45 (0.45)</u>	<u>0.7 (0.7)</u>	<u>1.3 (1.3)</u>
01 - Conduct Seminars and Information Programs	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
02 - Prepare Professional Papers, Brochures and Educational Films	0.15 (0.15)	0.2 (0.2)	0.5 (0.5)
03 - Prepare Textbooks and Handbooks	0.2 (0.2)	0.3 (0.3)	0.5 (0.5)

All of the budgets as individually presented above for the Hot Water Subprogram are presented in Table 28.

Schedules and Milestones

The overall scheduling and milestones for the various tasks of research recommended for the Hot Water resource are as shown in Figures 7-9. Milestones and activities shown concentrate on the first five-year period. The A Budget provides for a single, 10 MWe pilot plant at one of the three candidate sites. The B and C Budgets provide for two larger (20 MWe) pilot plants, each of different design or power cycles, to be selected from six candidate sites. The C Budget provides the greatest assurance of achieving all of the objectives. The most significant or critical POCE's in this project are those involving: (1) drilling of suitable production wells, (2) realization of effective reinjection techniques, (3) piloting of a satisfactory cycle, (4) solution of thermochemical and scaling problems,

(5) realization of adequate pumping equipment, (6) resolution of seismicity and/or subsidence problems, and (7) successful resolution of the major environmental problems related to waste -- liquids, solids and gases.

TABLE 28. Summary of Recommended Budgets for Hot
Water Resource Five- (and Ten-) Year
Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>TOTAL</u>	<u>31.1 (37.0)</u>	<u>40.8 (56.2)</u>	<u>77.7 (94.5)</u>
<u>H-00 Resource Scoping and Planning</u>	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)
<u>H-02 Resource Assessment</u>	<u>1.9 (1.9)</u>	<u>2.6 (2.6)</u>	<u>6.8 (6.8)</u>
01 - Resource Identification	1.5 (1.5)	1.8 (1.8)	4.0 (4.0)
02 - Resource Evaluation: Quality, Quantity and General Features	0.15(0.15)	0.3 (0.3)	0.8 (0.8)
03 - Chemical, Physical, Geological and Geothermal Properties	0.25(0.25)	0.5 (0.5)	2.0 (2.0)
<u>H-03 Resource Modeling</u>	<u>0.5 (0.5)</u>	<u>0.6 (0.6)</u>	<u>1.0 (1.0)</u>
01 - Detailed Definition and Description of Resource	0.5 (0.5)	0.6 (0.6)	1.0 (1.0)
<u>H-04 Reservoir Investigations - Production Wells</u>	<u>1.5 (1.5)</u>	<u>2.5 (2.5)</u>	<u>4.2 (4.2)</u>
01 - Drilling of Production Wells	1.2 (1.2)	1.7 (1.7)	3.0 (3.0)
02 - Characterization of Production Wells	0.3 (0.3)	0.8 (0.8)	1.2 (1.2)
<u>H-05 Reservoir Investigation - Stimulation</u>	<u>0.4 (0.4)</u>	<u>0.7 (0.7)</u>	<u>1.2 (1.2)</u>
01 - Investigation of Methods and Effectiveness of Flow Stimulation	0.4 (0.4)	0.7 (0.7)	1.2 (1.2)
<u>H-06 Reinjection Technology</u>	<u>1.5 (1.5)</u>	<u>2.0 (2.0)</u>	<u>2.5 (2.5)</u>
01 - Develop Geologic and Hydrologic Data and Mechanisms by Which Effective Reinjection Can Be Assured	1.5 (1.5)	2.0 (2.0)	2.5 (2.5)
<u>H-07 Power Generation Cycles</u>	<u>0.15(0.15)</u>	<u>0.2 (0.2)</u>	<u>0.4 (0.4)</u>
01 - Determine Most Appropriate and Economic Cycle	0.075(0.075)	0.1 (0.1)	0.2 (0.2)
02 - Selection of Optimum Binary Fluid	0.075(0.075)	0.1 (0.1)	0.2 (0.2)
<u>H-08 Thermochemistry</u>	<u>0.5 (0.5)</u>	<u>1.0 (1.0)</u>	<u>2.7 (2.7)</u>
01 - Investigate Thermochemistry of Resource	0.1 (0.1)	0.15(0.15)	0.6 (0.6)
02 - Study Corrosivity with Likely Materials	0.2 (0.2)	0.5 (0.5)	0.9 (0.9)
03 - Erosivity of Entrained Solids and Precipitates	0.1 (0.1)	0.1 (0.1)	0.6 (0.6)
04 - Study Scaling of Process Surfaces and Its Control	0.1 (0.1)	0.25(0.25)	0.6 (0.6)

TABLE 28. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-09 Equipment Research, Testing and Design</u>	<u>7.6 (7.6)</u>	<u>9.5 (9.5)</u>	<u>14.0 (14.50)</u>
01 - Pumping Equipment	0.6 (0.6)	0.75 (0.75)	0.75 (0.75)
02 - Heat Transfer Equipment	0.5 (0.5)	0.75 (0.75)	0.75 (0.75)
03 - Solids-Liquids Separators	0.1 (0.1)	0.2 (0.2)	0.5 (0.5)
04 - Fluid Transport Facilities	0.1 (0.1)	0.2 (0.2)	0.5 (0.5)
05 - Instrumentation for Measurement and Control	0.5 (0.5)	0.6 (0.6)	2.0 (2.0)
06 - Construct, Test and Modify Prototype Equipment	5.0 (5.0)	6.0 (6.0)	6.5 (7.0)
07 - Test Operation of Major Cycle Equipment on Nongeothermal Hot Water Source (Existing Thermal Power Plant)	0.8 (0.8)	1.0 (1.0)	3.0 (3.0)
<u>H-10 Pilot Plant Design</u>	<u>1.0 (1.0)</u>	<u>1.5 (1.5)</u>	<u>2.0 (2.0)</u>
01 - Complete Detailed Design of Pilot Plant	1.0 (1.0)	1.5 (1.5)	2.0 (2.0)
<u>H-11 Pilot Plant Construction</u>	<u>7.0 (7.0)</u>	<u>8.0 (12.0)</u>	<u>11.6 (15.0)</u>
01 - Construction	6.5 (6.5)	7.5 (11.0)	11.0 (13.8)
02 - Preoperative Testing	0.5 (0.5)	0.5 (1.0)	0.6 (1.2)
<u>H-12 Pilot Plant Operation</u>	<u>0.0 (2.5)</u>	<u>0.0 (4.0)</u>	<u>1.0 (5.0)</u>
01 - Operation	0.0 (2.5)	0.0 (4.0)	1.0 (5.0)
<u>H-13 Supporting Research</u>	<u>5.7 (10.0)</u>	<u>7.6 (15.0)</u>	<u>21.1 (30.0)</u>
01 - Drilling Research for Large Diameter Holes	3.3 (6.0)	3.6 (7.0)	10.0 (15.0)
02 - Large Deep-Well Pump Research	1.7 (2.5)	2.0 (4.0)	4.0 (5.0)
03 - Drilling	0.5 (1.0)	1.0 (2.0)	4.0 (6.0)
04 - Equipment-Deep Well Pumps	0.2 (0.5)	1.0 (2.0)	3.1 (4.0)
<u>H-14 Environmental Studies</u>	<u>1.45 (1.45)</u>	<u>2.1 (2.1)</u>	<u>5.2 (5.2)</u>
01 - Selection of Specific Resources on the Basis of Economic, Social, Political and Environmental Factors	0.2 (0.2)	0.4 (0.4)	1.0 (1.0)
02 - Compliance with Environmental Regulations and Requirements	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)

TABLE 28. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>H-14 Environmental Studies (contd)</u>			
03 - Seismic and Subsidence Investigations and Countermeasures Research	0.5 (0.5)	0.6 (0.6)	1.6 (1.6)
04 - Environmental Monitoring	0.15 (0.15)	0.3 (0.3)	0.5 (0.5)
05 - Site Survey	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
06 - Research on Cleanup Processes and Equipment for Waste Gases, Liquids and Solids	0.4 (0.4)	0.4 (0.4)	1.5 (1.5)
<u>H-15 Power Economics and Analysis</u>	<u>0.35 (0.35)</u>	<u>0.5 (0.5)</u>	<u>0.7 (0.7)</u>
01 - Refine Estimates of Costs for Large-Scale Plants	0.25 (0.25)	0.3 (0.3)	0.4 (0.4)
02 - Optimization of Use of Reservoir	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
<u>H-16 Multiple Use of Resource</u>	<u>0.6 (0.6)</u>	<u>0.8 (0.8)</u>	<u>1.5 (1.5)</u>
01 - Review and Evaluate Multiple Use Prospects	0.1 (0.1)	0.1 (0.1)	0.25 (0.25)
02 - Assessment of Potential Mineral Values	0.1 (0.1)	0.1 (0.1)	0.25 (0.25)
03 - Research on and Evaluation of Recovery Processes	0.4 (0.4)	0.6 (0.6)	1.0 (1.0)
<u>H-17 Utilization Promotion</u>	<u>0.45 (0.45)</u>	<u>0.7 (0.7)</u>	<u>1.3 (1.3)</u>
01 - Conduct Seminars and Information Programs	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
02 - Prepare Professional Papers, Brochures and Educational Films	0.15 (0.15)	0.2 (0.2)	0.5 (0.5)
03 - Prepare Textbooks and Handbooks	0.2 (0.2)	0.3 (0.3)	0.5 (0.5)

FIGURE 7. Hot Water Geothermal Power (Above 180°C) - A Budget (Fiscal Year)

FIGURE 8. Hot Water Geothermal Power (Above 180°C) - B Budget (Fiscal Year)

FIGURE 9. Hot Water Geothermal Power (Above 180°C) - C Budget (Fiscal Year)

FIGURE 9. (continued)

B. WARM WATER

As defined in this program, warm waters are those of low salinity (less than 3% by weight of dissolved solids) and temperatures between 150°C and 180°C in the reservoir. Such waters are expected to be relatively near the surface and probably comprise the most extensive and available geothermal resource. In composition such waters contain the same variety of dissolved solids and gases but typically in lesser amounts than found in waters of higher temperatures.

Location

As in the case of the hot water resource, the common occurrence of surface hot springs is indicative of the widespread existence of water of moderate temperatures. The assessment of such surface evidence to provide an appraisal of the resource at depth or its point of origin is a promising but uncertain method of assessment. Costly and extensive drilling of test wells provides the only sure means of establishing the data necessary to assure that the resource is a suitable one for power recovery.

As in the case of hot water, drilling for oil and gas has resulted in the discovery and location of warm water resources.

Value of Resource

Although sizeable resources are indicated in exploration already done, such as in the Imperial Valley of California, extensive subsurface exploration is still required to establish the size of even these resources.

From some preliminary estimates made by Bechtel,⁽¹⁾ the identified resources (median estimate) for liquid-dominated geothermal resources are as indicated below:

(1) M. Carasso, A Technological Assessment of Geothermal Energy Resource Development, Bechtel Corp., August 1975.

	<u>1985 Normal</u>	<u>1985 Crash</u>	<u>2000 Normal</u>	<u>2000 Crash</u>
Identified Liquid-Dominated Resources (10^6 Mwt. yrs)	10	1000	50	1000

The BNW staff estimates that of this total liquid-dominated resource about 70% will be warm water as defined in this study. On this basis, the expected size of the resource is:

	<u>1985 Normal</u>	<u>1985 Crash</u>	<u>2000 Normal</u>	<u>2000 Crash</u>
Identified Warm Water Resource (10^6 Mwt. yrs)	7	700	35	700

Planning studies have been conducted for demonstration plants at Raft River, Idaho (by Aerojet under ERDA contract) and Imperial Valley, California (by Ben Holt Co and San Diego Gas and Electric under ERDA-EPRI contract).

State-of-the-Art

To date no geothermal warm water power recovery systems have been operated for prolonged periods in the U.S. Anderson⁽¹⁾ has described a binary fluid cycle using isobutane. For warm waters so little steam can be obtained by flashing, it is probable that power generation will involve some alternate cycle such as the binary fluid one. Alternative processes such as total flow cannot be used until their feasibility and benefits have been firmly established. Such results can be achieved in this program but late in the ten-year period.

Problems

The principal problems to be encountered in the utilization of geothermal warm waters for power production are in many ways similar to those

(1) Geothermal Energy Resources, Production, Stimulation. Paul Kruger and Carel Otte, editors. Stanford University Press, Stanford, California.

for hot water. The major difference is the infeasibility of using the warm waters directly as working fluids. This requires the development of binary fluid cycles. These waters also require pumping since they will not self pump.

Development Strategy

The planned project research for this subprogram is similar to that for hot water. The major difference lies in an emphasis on binary fluid cycles and downhole pumping. The special situation at Brady Hot Springs, which may be considered for an early POCE, is also funded under this subprogram. The recommended A, B and C Budgets for the projects are shown in the Project Summary Table 29.

Projects

The projects recommended for research support are identical with those proposed for hot water due to the similarity of the two resource types. The funding requirements for the tasks under conditions of low, medium and high budgets, however, differ at many points to a considerable extent and are shown in the Summary Table at the end of this section (Table 30).

The relatively very low, five-year A Budget is accounted for by the intended joint participation in a power project originally proposed for Brady Hot Springs, Nevada. For this project much of the work normally covered by the various projects is already largely completed or is regarded as not required under these special circumstances. Furthermore, significant differences in overall budgeting at the B and C levels appear primarily under projects C-04 Production Wells, C-07 Power Cycles, C-09 Equipment Research, C-11 Pilot Plant Construction, C-12 Pilot Plant Operation, and C-13 Supporting Research. These tasks are presented in the Appendix.

Schedules and Milestones

The scheduling and milestones for the various tasks of research recommended for the Warm Water resource are as shown in Figures 10-12. The

TABLE 29. Summary of Recommended Project Budgets
for Warm Water Resource Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>8.9 (19.325)</u>	<u>37.4 (46.4)</u>	<u>72.9 (87.25)</u>
C-00 Scoping and Planning	0.2 (0.2)	0.5 (0.5)	0.5 (0.5)
C-02 Assessment	0.5 (0.5)	2.6 (2.6)	6.8 (6.8)
C-03 Modeling	0.2 (0.2)	0.6 (0.6)	1.0 (1.0)
C-04 Production Wells	0.2 (0.2)	2.5 (2.5)	6.2 (6.2)
C-05 Stimulation	0.0 (0.4)	0.7 (0.7)	1.2 (1.2)
C-06 Reinjection	0.0 (0.5)	2.0 (2.0)	2.5 (2.5)
C-07 Power Cycles	0.0 (0.125)	0.2 (0.2)	0.3 (0.3)
C-08 Thermochemistry	0.5 (0.5)	1.0 (1.0)	2.7 (2.7)
C-09 Equipment Research	1.0 (1.0)	5.3 (5.3)	8.7 (9.3)
C-10 Pilot Plant Design	0.2 (0.2)	1.5 (1.5)	2.0 (2.0)
C-11 Pilot Plant Construction	3.3 (3.3)	9.0 (11.0)	12.2 (16.0)
C-12 Pilot Plant Operation	0.0 (2.5)	0.0 (3.0)	1.00 (5.00)
C-13 Supporting Research	1.0 (7.3)	7.6 (13.6)	19.0 (25.00)
C-14 Environmental Studies	1.0 (1.0)	2.1 (2.1)	5.2 (5.2)
C-15 Power Economics	0.35 (0.35)	0.5 (0.5)	0.75 (0.75)
C-16 Multiple Uses	0.0 (0.6)	0.7 (0.7)	1.5 (1.5)
C-17 Utilization Promotion	0.45 (0.45)	0.6 (0.6)	1.3 (1.3)
Total Budget	8.9 (19.325)	37.4 (4.64)	72.9 (87.25)

milestone charts concentrate on the first five-year period. The A Budget for the five-year program is dependent on expeditious and joint participation in the Brady Hot Springs (or similar) power project for which most of the basic work is completed. The B and C Budgets afford a more extensive investigation to establish more sites for pilot plant possibilities. The more significant or critical POCE's in the project are those involving effective reinjection techniques, piloting of the binary fluid cycle, solution of thermochemical and scaling problems, realization of adequate pumping equipment, resolution of seismicity and/or subsidence problems, if any, and successful resolution of major environmental problems related to waste liquids, solids or gases.

TABLE 30. Summary of Recommended Budgets for
Warm Water Resource Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>8.9 (19.325)</u>	<u>37.4 (46.400)</u>	<u>72.9 (87.250)</u>
<u>C-00 Resource Scoping and Planning</u>	<u>0.200(0.200)</u>	<u>0.500(0.500)</u>	<u>0.500(0.500)</u>
<u>C-02 Resource Assessment</u>	<u>0.500(0.500)</u>	<u>2.600(2.600)</u>	<u>6.800(6.800)</u>
01 - Resource Identification	0.100(0.500)	1.800(1.800)	4.000(4.000)
02 - Resource Evalaution: Quality, Quantity and General Features	0.150(0.150)	0.300(0.300)	0.800(0.800)
03 - Chemical, Physical, Geological and Geothermal Properties	0.250(0.250)	0.500(0.500)	2.000(2.000)
<u>C-03 Resource Modeling</u>	<u>0.200(0.200)</u>	<u>0.600(0.600)</u>	<u>1.000(1.000)</u>
01 - Detailed Definition and Description of Resource	0.200(0.200)	0.600(0.600)	1.000(1.000)
<u>C-04 Reservoir Investigations - Production Wells</u>	<u>0.200(0.200)</u>	<u>2.500(2.500)</u>	<u>6.200(6.200)</u>
01 - Drilling of Production Wells	0.150(0.150)	1.700(1.700)	4.200(4.200)
02 - Characterization of Production Wells	0.050(0.050)	0.800(0.800)	2.000(2.000)
<u>C-05 Reservoir Investigation - Stimulation</u>	<u>0.0 (0.400)</u>	<u>0.700(0.700)</u>	<u>1.200(1.200)</u>
01 - Investigation of Methods and Effectiveness of Flow Stimulation	0.0 (0.400)	0.700(0.700)	1.200(1.200)
<u>C-06 Reinjection Technology</u>	<u>0.0 (0.500)</u>	<u>2.000(2.000)</u>	<u>2.500(2.500)</u>
01 - Develop Geologic and Hydro- logic Data and Mechanisms by Which Effective Reinjection Can Be Assured	0.0 (0.500)	2.000(2.000)	2.500(2.500)
<u>C-07 Power Generation Cycles</u>	<u>0.0 (0.125)</u>	<u>0.200(0.200)</u>	<u>0.300(0.300)</u>
01 - Determine Most Appropriate and Economic Cycle	0.0 (0.065)	0.100(0.100)	0.150(0.150)
02 - Selection of Optimum Binary Fluid	0.0 (0.060)	0.100(0.100)	0.150(0.150)

TABLE 30. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>C-08 Thermochemistry</u>	<u>0.500(0.500)</u>	<u>1.000(1.000)</u>	<u>2.700(2.700)</u>
01 - Investigate Thermochemistry of Resource	0.100(0.100)	0.150(0.150)	0.600(0.600)
02 - Study Corrosivity with Likely Materials	0.200(0.200)	0.500(0.500)	0.900(0.900)
03 - Erosivity of Entrained Solids and Precipitates	0.100(0.100)	0.100(0.100)	0.600(0.600)
04 - Study Scaling or Process Surfaces and Its Control	0.100(0.100)	0.250(0.250)	0.600(0.600)
<u>C-09 Equipment Research, Testing and Design</u>	<u>1.000(1.000)</u>	<u>5.300(5.300)</u>	<u>8.700(9.300)</u>
01 - Pumping Equipment	0.100(0.100)	0.600(0.600)	0.750(0.700)
02 - Heat Transfer Equipment	0.100(0.100)	0.600(0.600)	0.750(0.750)
03 - Solids-Liquids Separators	0.050(0.050)	0.150(0.150)	0.400(0.400)
04 - Fluid Transport Facilities	0.050(0.050)	0.150(0.150)	0.400(0.400)
05 - Instrumentation for Measurement and Control	0.100(0.100)	0.500(0.500)	1.000(1.000)
06 - Construct, Test and Modify Prototype Equipment	0.600(0.600)	2.500(2.500)	4.000(4.000)
07 - Test Operation of Major Cycle Equipment on Non-geothermal Hot Water Source (Existing Thermal Power Plant)	0.000(0.000)	0.800(0.800)	2.000(2.000)
<u>C-10 Pilot Plant Design</u>	<u>0.200(0.200)</u>	<u>1.500(1.500)</u>	<u>2.000(2.000)</u>
01 - Design of Pilot Plant	0.200(0.200)	1.500(1.500)	2.000(2.000)
<u>C-11 Pilot Plant Construction</u>	<u>3.300(3.300)</u>	<u>9.000(11.000)</u>	<u>12.200(16.000)</u>
01 - Construction	3.000(3.000)	8.400(10.000)	11.600(14.700)
02 - Preoperative Testing	0.300(0.300)	0.600(1.000)	0.600(1.300)
<u>C-12 Pilot Plant Operation</u>	<u>0.0 (2.500)</u>	<u>0.0 (3.000)</u>	<u>1.000(5.000)</u>
01 - Operation	0.0 (2.500)	0.0 (3.000)	1.000(5.000)
<u>C-13 Supporting Research</u>	<u>1.000(7.300)</u>	<u>7.600(13.600)</u>	<u>19.000(25.000)</u>
01 - Drilling Research for Large Diameter Holes	0.400(3.300)	3.600(5.000)	9.500(10.000)
02 - Large Deep-Well Pump Research	0.100(1.000)	2.000(3.000)	4.000(6.000)
03 - Drilling	0.300(2.000)	1.000(3.500)	3.000(5.500)
04 - Equipment-Deep Well Pumps	0.200(1.000)	1.000(2.100)	2.500(3.500)

TABLE 30. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>C-14 Environmental Studies</u>	<u>1.000(1.000)</u>	<u>2.100(2.100)</u>	<u>5.200(5.200)</u>
01 - Selection of Specific Resource on the Basis of Economic, Social, Political and Environmental Factors	0.100(0.100)	0.400(0.400)	1.000(1.000)
02 - Compliance with Environmental Regulations and Requirements	0.100(0.100)	0.200(0.200)	0.300(0.300)
03 - Seismic and Subsidence Investigations and Counter-measures Research	0.300(0.300)	0.600(0.600)	1.600(1.600)
04 - Environmental Monitoring	0.100(0.100)	0.300(0.300)	0.500(0.500)
05 - Site Survey	0.100(0.100)	0.200(0.200)	0.300(0.300)
06 - Research on Cleanup Processes and Equipment for Waste Gases, Liquids and Solids	0.300(0.300)	0.400(0.400)	1.500(1.500)
<u>C-15 Power Economics and Analysis</u>	<u>0.350(0.350)</u>	<u>0.500(0.500)</u>	<u>0.750(0.750)</u>
01 - Refine Estimates of Costs Large-Scale Plants	0.250(0.250)	0.300(0.300)	0.400(0.400)
02 - Optimization of Use of Reservoir	0.100(0.100)	0.200(0.200)	0.350(0.350)
<u>C-16 Multiple Use of Resource</u>	<u>0.0 (0.600)</u>	<u>0.700(0.700)</u>	<u>1.500(1.500)</u>
01 - Review and Evaluate Multiple Use Prospects	0.0 (0.100)	0.100(0.100)	0.250(0.250)
02 - Assessment of Potential Mineral Values	0.0 (0.100)	0.100(0.100)	0.250(0.250)
03 - Research on and Evaluation of Recovery Processes	0.0 (0.400)	0.500(0.500)	1.000(1.000)
<u>C-17 Utilization Promotion</u>	<u>0.450(0.450)</u>	<u>0.600(0.600)</u>	<u>1.300(1.300)</u>
01 - Conduct Seminars and Information Programs	0.100(0.100)	0.150(0.150)	0.300(0.300)
02 - Prepare Professional Papers, Brochures and Educational Films	0.150(0.150)	0.200(0.200)	0.500(0.500)
03 - Prepare Textbooks and Handbooks	0.200(0.200)	0.250(0.250)	0.500(0.500)
TOTAL BUDGETS	8.9 (19.325)	37.4 (46.400)	72.9 (87.250)

FIGURE 10. Warm Water Geothermal Power (Below 180°C) - A Budget (Fiscal Year)

FIGURE 11. Warm Water Geothermal Power (Below 180°C) - B Budget (Fiscal Year)

FIGURE 12. Warm Water Geothermal Power (Below 180°C) - C Budget (Fiscal Year)

C. HOT DRY ROCK

The concept of using the "heat of the earth" for power generation can become a reality through exploitation of hot dry rock areas of the earth's crust. These hot dry rock areas consist of igneous intrusions in the earth's crust and may be found at moderate depths of about 3 kilometers.⁽¹⁾ Hot dry rock "deposits" are estimated by BNW, USGS and others to be fairly numerous and contain the major fraction of potentially available geothermal power resources. The critical tasks facing the successful exploitation of this resource is: (1) determining location and size of deposits, (2) fracturing the formation or otherwise increasing its permeability, (3) introduction of the circulating fluid, and (4) effectively using the circulating fluid for heat extraction and power production.

Location^(1,2,3)

Hot dry rock occurs in two different, generally impermeable configurations: (1) It is estimated that hot impermeable rock underlies most of the United States, even in regions of subnormal heat flow. This estimate is based upon the idea that aquifers will only penetrate to some limiting depth, and that the rocks at greater depths have either crystallized from a magma or are so highly recrystallized that they have very low permeability. (2) During geologic time, magma has forced its way locally up into the earth's mantle and outer crust as a result of geological processes. These intrusions consist of hot (~350°C), relative dry rock at moderate depths. The low viscosity of basaltic magmas causes them to form relatively thin intrusive bodies or to be extruded as lava flows, but intermediate and

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- (1) A Feasibility Study of a Plowshare Geothermal Power Plant, sponsored by the U.S. AEC and the American Oil Shale Corp., April 1971.
 - (2) Walter J. Hickel, Geothermal Energy. Final report of the Geothermal Resources Research Conference, Battelle Seattle Research Center, Seattle, WA, September 18-20, 1972.
 - (3) Battelle Pacific Northwest Laboratories, A Special Initiative Research Proposal for the Evaluation of a Geothermal Area of Abnormally High Heat Flow at Marysville, Montana, February 2, 1973.

granitic magmas are very viscous and hence form plug-like plutons. A solid but still hot intrusion of granitic rock close to the surface is a likely candidate for a dry geothermal resource.

In the western United States, the volume of granitic rock that intruded during the middle Cretaceous period (80 to 110 million years ago) is several hundred times the volume that has been intruded since then. However, there are many important young intrusions, and they form a broad band that passes from north to south through western Utah and eastern Nevada. Gilluly⁽¹⁾ has suggested a continuous history of intrusions from Cretaceous to the recent (see Figure 13). Thus it is reasonable to expect that numerous granitic intrusions have occurred west of the Continental Divide during the past two or three million years. These intrusions may appear as anomalous regions of high temperature gradients with depth; these anomalies have been estimated⁽²⁾ to be from 150°C to 300°C/km compared to normal earth gradient of about 20°C to 30°C/km. Thus one might expect to find useful energy at depths of 1.5 to 3 km.

Two hot rock geothermal sites were under investigation during this study. These locations appeared to be the most likely sources of early power generation from the Hot Rock resource. The first site is being investigated by Los Alamos Scientific Laboratory (LASL) in the Jemez Mountains a few miles west of the Valles Caldera, about 30 miles west of LASL.⁽²⁾ This site is particularly suitable for a field experiment. In recent drilling a temperature of 200°C was encountered at a depth of 3000 meters. The formation was found to be tight and hydrofracturing experiments were successfully conducted. This location is termed the "Valles Caldera" site.

(1) James Gilluly, "The Tectonic Evolution of the Western U.S." Geol. Soc. London Quart. Journ., Vol. 119, pp. 133-174, 1963.

(2) Morton Smith, R. Potter, D. Brown, and R.L. Aamodt, "Induction and Growth of Fractures in Hot Rock", Geothermal Energy Resources, Production, Stimulation. Paul Kruger and Carel Otte, editors, Stanford University Press, Stanford, CA, pp. 251-268, 1973.

FIGURE 13.

Granitic rocks of Mesozoic and Cenozoic age in the western United States. The age assignments are based in part on all of the radiometric ages published up to July 1962. After Gilluly, "The Tectonic Evolution of the Western United States."

A second site, discovered by Dr. David Blackwell operating under National Science Foundation (NSF) grants and with additional assistance from the U.S. Geological Survey (USGS), is an area of abnormally high heat flow near Marysville, Montana. The heat flow for the Marysville area ranges from 3.1 to 19.5 $\mu\text{cal}/\text{cm}^2\text{-sec.}$ ⁽¹⁾ In comparison, the average for western Montana is 1.9 $\mu\text{cal}/\text{cm}^2\text{-sec.}$ The preliminary measurements and estimates made at this site indicated gradients as high as 240°C/km. The anomaly was thought to be a near-surface granitic pluton 20,000 to 80,000 years old. Recent drilling at the site has proved it to be a hydrothermal convective system of 100°C water at 400 meters depth.

Current plans of ERDA, in cooperation with USGS, call for further exploration of other areas for the location of hot dry rock. Hopefully this program will discover an area of 300°-350°C in which to conduct the experiments originally envisioned for Marysville.

Value of Resource

Hot dry rock is estimated to be the largest of the geothermal resources. Estimates of thermal reserve resources range from very high values such as $3,000,000 \times 10^6$ Mwt-years to values as low as 5×10^6 Mwt-years.^(2,3) Median values of about 1,000 to $10,000 \times 10^6$ Mwt-years appear reasonable.⁽²⁾ The median estimates range from 5 to 10 times the available thermal energy from the sum of all other geothermal resources.⁽²⁾ These estimates provide a very bright picture for power generation of several thousand MWe from hot dry rock, but much research and engineering remain to be accomplished in exploration, assessment, drilling, fracturing, and utilization prior to commercialization of the resource. However, successful development of one major hot rock geothermal site will eventually provide significant power production.

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- (1) D.D. Blackwell, "Heat Flow Near Marysville, Montana" (Abstract), EOS Trans., American Geophysical Union, Vol. 51, p. 834, 1970.
 - (2) M. Carasso, A Technological Assessment of Geothermal Energy Resource Development, Bechtel Corp. August 1975.
 - (3) Harry Perry, Resources for the Future, Inc., private communication, p. 149 of attached material, May 30, 1973.

State-of-the-Art

Major progress is being made in several critical research areas for hot dry rock power development. These programs are described in detail in the project summary and task sheet sections. The programs are reviewed briefly here: (1) Exploration and Assessment methods now being employed include drilling and logging, gravity analyses, and geologic characteristics identification and mapping, along with electrical, photographic, and electromagnetic methods still under development. Additionally, progress is being made in locating and exploring regions likely to have dry rock resources. The identification and exploration of the Valles Caldera and Marysville sites have been described above.

(2) Reservoir Development both in the modeling and fracturing/stimulation areas has made progress. This progress has been accomplished primarily at LASL.^(1,2) This work includes both the in-field hydrofracturing and computer modeling at Valles Caldera. The Valles Caldera program has demonstrated successful hydrofracturing in its first drill hole in ~100°C rock at a depth of 2,500 feet. Rock fractures can be opened and extended at pressures greater than 1,200 psiph (plus the hydrostatic head) and maintained statically at 900 psiph. The rock fractures extended vertically and were oriented azimuthally in the direction of the tectonic stress field. The LASL Reservoir Computer Modeling Program predicted the results quite well. Crack extent was monitored by water consumption, compaction, and echo (radar) techniques. Water consumption at static crack conditions (~900 psiph) was low. Permeability of the base rock is in the order of micro-darcys. New bore holes are planned for both hydrofracturing and setting up circulating loops. These are described in the task write-ups.

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- (1) Morton Smith, R. Potter, D. Brown and R.L. Aamodt, "Induction and Growth of Fractures in Hot Rock", Geothermal Energy Resources, Production, Stimulation. Paul Kruger and Carel Otte, editors. Stanford University Press, Stanford, CA, pp. 223-230, 1973.
 - (2) Morton Smith, Los Alamos Scientific Laboratory, private communication, December 12, 1973.

Additionally, explosive fracturing and stimulation have been researched for many years in the oil industry and more recently, specifically for geothermal fields.⁽¹⁾ Stimulation with nuclear techniques along with reservoir optimization has also been studied.^(2,3) The hot rock resource will benefit from research and engineering methods and equipment developed in subprograms for the other geothermal resources. The interactions with these subprograms are described in the task and project descriptions. Some of the most prominent items include: high temperature drilling techniques which have been developed in oil and brine studies; binary fluid cycle power plant development (for moderate hot rock and end-of-life field hot rock applications) which is progressing as part of the hot water resource development and through several commercial development programs; downhole pumps (the need for these has not yet been determined for the hot rock resource) which will be developed for the brine and hot and warm water resources; reinjection, fluid flow, fluid cleanup, heat exchanger and turbine technology from the currently exploited dry steam resource, coupled with research programs for the water resources which are directly applicable to hot dry rock.

Problems

Power generation from the hot dry rock resource faces many research and engineering challenges throughout the program which leads to commercial power production. However, a well-planned and executed research program can solve these problems and provide an important power resource for the United States. This section highlights the major problems which are discussed in detail in the project and task write-ups: (1) Location, exploration, hot formation drilling, and assessment of the resource are the first major problems. As noted in the Location and State-of-the-Art sections above, the capabilities for pinpointing the resource and determining its

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- (1) Geothermal Energy Resources, Production, Stimulation, Paul Kruger and Carel Otte, editors. Stanford University Press, Stanford, CA, pp. 231-250, 269-292, 1973.
 - (2) Op cit., pp. 315-334.
 - (3) A Feasibility Study of a Plowshare Geothermal Power Plant, sponsored by the U.S. AEC and the American Oil Shale Corp., April 1971.

size and physical properties are very limited. (2) Fracturing and establishing the reservoir flow patterns are major challenges, although initial hydrofracturing success has been demonstrated in the Valles Caldera program (see State-of-the-Art section). Well interfacing, crack control, crack and particle size, propping, and water loss control must be engineered for commercial use.

(3) The reinjection, fluid flow, and thermochemistry areas have several critical research problems. These include developing the high flow pressurizing pumps for fluid reinjection and pressurizing for hydrofracturing; circulating water and steam (for direct cycle) demineralizing in combination with processes for piping and equipment cleanup; and field and fluid state optimization problems associated with hole arrays, size, diameters, pipe runs and trade-offs between pressurized and direct steam cycles along with reservoir lifetimes and temperatures. (4) Environmental aspects represent a major research challenge from the standpoints of subsidence, seismic aggravation, water consumption, and possibly waste product disposal.

(5) Equipment development for the various power generation modes presents several research and engineering challenges. These include, for the pressurized cycle: the heat exchangers, piping, steam (or organic vapor) generators from the hot-side cleanup processes and heat transfer standpoints, and the power generation equipment for the organic (secondary) cycle as well as the relocatable aspects of the end-of-(reservoir)-life (EOL) plant.* For the direct steam cycle, the list of major equipment engineering problems includes the pressurized cycle components mentioned above plus the generating equipment, condensers, gas removal, steam cleanup,

* Most efficient use of the geothermal heat source will require power generation at the lower temperature end of the source lifetime. This may be accomplished with an end-of-life binary (organic) cycle plant which incorporates the design features of the Valles Caldera plant (assuming it is a binary cycle) and other geothermal resources binary cycle plants. The EOL plant will be portable and used in conjunction with a power generation program at geothermal sites for coupling into the system at end-of-life for exploiting cooler wells in the field system.

and bore casing plate-out problems. (6) Other major problem areas for the more advanced projects include the direct organic cycle equipment, nuclear applications, and mineral recovery.

Development Strategy

Production of power from hot dry rock requires the longest lead time of all the geothermal resources. Many important research tasks can be accomplished in the first five years to demonstrate the resource power production viability. Two types of hot rock deposits are differentiated on the basis of reservoir temperature. The first type, assumed to be typified by Valles Caldera, is the generally hot ($\sim 250^{\circ}\text{C}$) region of an anomaly in the normal earth thermal gradient. It is thought that this type of anomaly is more common than the one sought at Marysville. A hotter intrusion, of $300\text{--}350^{\circ}\text{C}$, can be harnessed for power production in a manner different from Valles Caldera.

Thus the research program should pursue two paths: (1) power generation with moderately hot rock, such as presumed at Valles Caldera, using a binary fluid cycle, i.e., pressurized water as the circulating primary geothermal fluid with a secondary organic working fluid, and (2) power generation using hotter intrusions by direct steam and/or pressurized water-steam cycles. The discovery of a high temperature site ($300\text{--}350^{\circ}\text{C}$) will greatly enhance the development of this resource. In the original (1973) planning effort it was assumed that Marysville, Montana would yield such temperatures. In the various tables and Gantt charts which follow, such a high temperature has been designated "Marysville". As discussed in a previous paragraph, subsequent drilling at Marysville revealed that this site is a hydrothermal convective formation. Where the reader finds references to a "Marysville" project, he should recognize that this refers to an as-yet-undiscovered hot dry rock site of $300\text{--}350^{\circ}\text{C}$ temperature.

The designs of the five- and ten-year programs for the A, B and C Budgets are tabulated in Table 31. Basically, the A Budget provides for essential research and operating engineering demonstration loops in five years at the two sites, Valles Caldera and Marysville, and pilot generating

TABLE 31. Hot Dry Rock Resource Major Program
Projected Accomplishments and POCE's

Accomplishments	A BUDGET		B BUDGET		C BUDGET	
	5 Year	10 Year	5 Year	10 Year	5 Year	10 Year
POCE-Pilot Plants and Loops	Engineer circulation loops at Marysville and Valles Caldera.	Pilot generating plants operating at both sites.	Same as A plus alternative water cycle loop at Site 3.	Pilot generating plants operating at three sites.	Same as B plus loop operation for the Geoplex and direct organic cycles.	Pilot generating plants operating at five sites.
POCE-Auxiliary Systems and Processes	Hydrofracturing, fluid and component cleanup at two sites.	Mineral recovery chemistry; field expansion.	Same as A at three sites plus 1) mineral recovery, 2) some field expansion at Site 3, 3) demonstrated cleanup processes for three cycles, 4) explosive assist to hydrofracturing and well interfacing.	Mineral recovery pilot plant; field operation of components for three cycles.	Same as B plus equipment research and engineering for Geoplex and direct organic cycle; extensive explosive assist fracturing.	Same as B plus field operation of equipment at all five sites; mineral recovery pilot plants at multiple sites.
Research	Critical components and processes for two sites.	Same as 5-year.	Critical, major and some alternative research for three sites plus some supporting research and minimal ancillary projects.	Same as 5-year.	Same as B plus major alternative and new cycle research. Major supporting research projects and ancillary projects.	Same as 5-year.

plants operating in 1981 and 1982 respectively. The B Budget accelerates and expands the research tasks, focuses on new research areas, and provides an additional generating plant using an alternative (to Marysville) water cycle at a third site with circulating loops in five years and pilot generation plant operation in 1982. The alternative water cycle to the Marysville plant assumes that Marysville will choose a direct steam or pressurized water-steam cycle and the third site in the B Budget would develop the cycle not selected for Marysville. The C Budget expands the research and engineering programs into two advanced areas, the Geoplex* and the Direct Organic Cycle projects, as well as expands the basic task scopes and supporting research areas.

The above description is quite brief and the reader should refer to the project and task write-ups for the details of the hot rock program. Additionally, the tables, schedules, and critical path charts found in the latter part of this report further delineate the program rationales, sequences and requirements. It should be noted that the numbering scheme for the tasks is set up for computer analysis with sequential numbers (e.g., R-05-01, R-05-02, R-05-03, etc.) which do not require completion of preceding tasks. The exception is in the R-00 tasks, Program Scoping and Planning, which uses the same task numbers as their corresponding projects. Table 32 summarizes the A, B and C five- and ten-year budgets.

Projects

This section summarizes the projects which make up the hot dry rock geothermal program. In addition, task budget summaries are provided for each project and are tabulated for the total program at the end of this section (Table 48). The reader is also referred to Figures 14, 15 and 16 for the A, B and C five- and ten-year schedule charts. All major tasks and

*A "Geoplex" is defined here as a community whose power source is predominantly from geothermal power. The geothermal power source would provide electrical energy (~200 MWe), space heating, and process and industrial heat energy. Perhaps mineral sources from the geothermal wells can also be exploited.

TABLE 32. Summary of Recommended Project Budgets
for Hot Rock Resource Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>17.3(44.1)</u>	<u>68.4(102.1)</u>	<u>100.6(232.3)</u>
R-00 - Scoping & Planning	0.3(0.3)	0.9(0.9)	1.1(1.1)
R-02 - Assessment	2.1(2.1)	15.1(15.1)	16.5(16.5)
R-03 - Reservoir Develop. - Modeling	0.2(0.2)	0.4(0.4)	0.4(0.4)
R-05 - Reservoir Develop. - Fracturing & Simulation	5.0(7.0)	13.8(16.0)	36.8(39.0)
R-06 - Reinjection & Fluid Flow Tech.	4.1(4.1)	7.4(7.4)	7.4(7.4)
R-07 - Power Generation Cycles	0.2(0.2)	1.7(1.7)	1.9(1.9)
R-08 - Thermochemistry	2.0(2.0)	5.8(5.8)	6.3(6.3)
R-09 - Equipment Design, Fabrication & Test	3.1(7.0)	8.6(11.5)	9.6(12.5)
R-10 - Pilot Plant Design	(2.2)	1.8(3.3)	3.9(5.9)
R-11 - Pilot Plant Construc.	(12.0)	1.8(21.0)	3.8(111.0)
R-12 - Pilot Plant Operation	(5.0)	(7.5)	(15.0)
R-13 - Supporting Research	(0.7)	8.3(8.7)	8.3(8.7)
R-14 - Environmental Studies	0.2(0.7)	0.9(0.9)	1.5(1.7)
R-15 - Power Economics Anal.	0.1(0.3)	0.2(0.3)	0.5(0.6)
R-16 - Multiple Use of Res.	(0.2)	1.2(1.2)	1.5(1.5)
R-17 - Utilization Project	0	0.4(0.4)	1.0(1.0)

projects are shown in sequence for the hot dry rock resource in these figures.

R-00 Program Scoping and Planning

This task provides the basic planning task for the resource. It sets up the detailed program leading to commercial generation of power from the hot dry rock resource. This includes preliminary ground work for all projects to follow in the hot rock subprogram. These include the topics listed in Table 33. The Program Scoping and Planning tasks lay plans for future work, analyze and bound the problems facing each project, firm the project funding requirements and schedules, and review and select organizations to perform the project and task work. The A Budget focuses only on the critical items facing the Marysville and Valles Caldera developments and takes into account the accomplishments already in place at Marysville and Valles Caldera. The B Budget expands the focus to major items of development concern as well as performing ancillary tasks (projects) on a limited basis. The C Budget performs planning and scoping tasks applicable to the fully developing resource as well as completing planning for all ancillary tasks.

R-01 Exploration (Not Funded in This Resource Program)

This project is performed under the Exploration subprogram. No work is done in the A Budget since two sites, Valles Caldera and Marysville, have already been selected. The Exploration subprogram explores and designates the alternative water cycle site in the B Budget, as well as the Geoplex, and directs organic sites in the C Budget. Exploration methods specific to the hot dry rock resource will also be developed in the Exploration subprogram.

R-02 Assessment

This project determines the size, boundaries, thermal and physical properties of the resource fields. Further, it determines the initial resource development potential from the standpoints of permeability, fracturability and water containment performance. Portions of this project are performed under the Assessment subprogram. Limited assessment is done

TABLE 33. Summary of Recommended Budgets for Scoping
and Planning Project for Hot Dry Rock Resource
Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-00 Scoping and Planning</u>	<u>0.3(0.3)</u>	<u>0.9(0.9)</u>	<u>1.1(1.1)</u>
01 - Exploration	0	0	0
02 - Assessment	0.02(0.02)	0.05(0.05)	0.05(0.05)
03 - Reservoir Develop. - Modeling	0.01(0.01)	0.03(0.03)	0.03(0.03)
05 - Reservoir Develop. - Fracturing & Simulation	0.02(0.02)	0.07(0.07)	0.07(0.07)
06 - Reinjection & Fluid Flow Tech.	0.05(0.05)	0.1(0.1)	0.1(0.1)
07 - Power Generation Cycles	0.07(0.07)	0.2(0.2)	0.2(0.2)
08 - Thermochemistry	0.05(0.05)	0.1(0.1)	0.1(0.1)
09 - Equipment Design, Fabrication & Test	0.02(0.02)	0.06(0.06)	0.06(0.06)
10 - Pilot Plant Design	0.02(0.02)	0.04(0.04)	0.04(0.04)
11 - Pilot Plant Construc.	0	0	0
12 - Pilot Plant Operation	0	0.02(0.02)	0.02(0.02)
13 - Supporting Research	0.01(0.01)	0.02(0.02)	0.02(0.02)
14 - Environmental Studies	0.01(0.01)	0.02(0.02)	0.02(0.02)
15 - Power Economics Anal.	0	0	0
16 - Multiple Use of Resource	0	0	0
17 - Utilization Project	0.005(0.005)	0.02(0.02)	0.02(0.02)
19 - Site Selection & Eval.		0.05(0.05)	0.05(0.05)
21 - Alternate Cycle Eval.		0.05(0.05)	0.05(0.05)
23 - Alternate & Expanded Plant Designs		0.07(0.07)	0.07(0.07)
25 - Scoping Study, Geoplex			0.1(0.1)
27 - Direct Organic Cycle Plant Study			0.1(0.1)

in the A Budget since two sites, Valles Caldera and Marysville, have already been selected and are currently being assessed. This project, along with subprogram A, assesses the alternative water cycle site in the B Budget and the Geoplex and direct organic sites in the C Budget. Assessment methods specific to the hot dry rock resource will also be developed in the Assessment subprogram A, and applied in this project. Two critical items are accomplished in the five-year A Budget: the establishment of the potential of the Valles Caldera and Marysville sites as the two POCE pilot plant locations. The tasks and budgets for this project are summarized in Table 34.

TABLE 34. Summary of Recommended Budgets for Assessment Project for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-02 Assessment</u>	<u>2.1 (2.1)</u>	<u>15.1 (15.1)</u>	<u>16.5 (16.5)</u>
01 - Field Test-Valles Caldera	0.8 (0.8)	0.8 (0.8)	0.8 (0.8)
02 - Field Test - Marysville	0.9 (0.9)	0.9 (0.9)	0.9 (0.9)
03 - Assessment Methods	0.4 (0.4)	1.4 (1.4)	1.4 (1.4)
05 - Resource Exploration and Prospecting	-	12.0 (12.0)	12.0 (12.0)
06 - Geoplex Survey and Selection	-	-	1.0 (1.0)
08 - Direct Cycle Organic Site Selection	-	-	0.4 (0.4)

R-03 Reservoir Development - Modeling

This task further refines existing reservoir models and researches new models for reservoir behavior predictions. It will rely heavily on the already functioning modeling program at LASL.⁽¹⁾ It is applied initially at

(1) Morton Smith, R. Potter, D. Brown and R.L. Aamodt, "Induction and Growth of Fractures in Hot Rock", Geothermal Energy Resources, Production, Stimulation, Paul Kruger and Carel Otte, editors. Stanford University Press, Stanford, CA, pp. 251-268, 1973.

Valles Caldera and Marysville in the A Budget. While the model is exercised for other sites and reservoirs, this work does not appear in this project but will be part of the Reservoir Development Project - Fracturing and Stimulation, R-05, specific to each site. Project R-03 is given in Table 35 below.

TABLE 35. Summary of Recommended Budgets for Reservoir Development Project for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-03 Reservoir Development -</u>			
<u>Modeling</u>	<u>0.2 (0.2)</u>	<u>0.4 (0.4)</u>	<u>0.4 (0.4)</u>
01 - Modeling	0.2 (0.2)	0.4 (0.4)	0.4 (0.4)

R-04 Reservoir Development - Production Wells
(Not Funded for This Resource)

This project is not performed for the hot dry rock resource since the wells are formed as part of the following project, R-05.

R-05 Reservoir Development - Fracturing and Stimulation

This project provides the basic fracturing and field pressurization program for all fields developed under the hot rock program as well as research and engineering for fracturing and stimulation methods. The five-year A Budget focuses mainly on establishing the portions of the Marysville and Valles Caldera reservoirs for the POCE engineering circulation loops. Additionally, this budget provides limited research into conventional explosive applications. The ten-year A Budget provides the field expansion programs at the two sites for the pilot generating plants. The B and C Budgets provide expanded research programs particularly in the development of explosives to aid fracturing along with the initial fracturing and field expansion programs for the three new sites (one in the B Budget and two more in the C Budget). As pointed out earlier, some initial and successful hydrofracturing is taking place at Valles Caldera. The R-05 project and tasks are summarized in Table 36.

TABLE 36. Summary of Recommended Budgets for Reservoir Development-
Fracturing and Stimulation Project for Hot Dry Rock
Resource Five- (and Ten-) Year Budgets (in \$ millions).

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-05 Reservoir Develop.-</u> <u>Fracturing &</u> <u>Stimulation</u>	<u>5.0(7.0)</u>	<u>13.8(16.0)</u>	<u>36.8(39.0)</u>
01 - Field Test Frac- turing Studies Valles Caldera	2.0(2.0)	2.0(2.0)	2.0(2.0)
02 - Field Test Frac- turing Studies Marysville	1.0(1.0)	1.0(1.0)	1.0(1.0)
03 - Field Expansion Programs	1.2(3.3)	3.3(3.3)	3.2(3.3)
05 - High Explosive Selection & Application Design	0.1(0.1)	0.1(0.1)	0.1(0.1)
06 - High Explosive Application	0.2(0.2)	0.2(0.2)	0.2(0.2)
07 - High Explosive Field Tests	0.4(0.4)	0.4(0.4)	0.4(0.4)
09 - Advanced Stimula- tion Technology Updating	0.005(0.006)	0.005(0.006)	0.005(0.006)
11 - Site 3 Development, Fracturing, & Fluid & Heat Flow		3.0(3.0)	3.0(3.0)
12 - Production Site - Field Expansion Program		1.0(3.0)	1.0(3.0)
14 - High Explosives Applications Testing		2.0(2.0)	2.0(2.0)
16 - High Explosives Engineering for Special Applica- tions		1.0(1.0)	1.0(1.0)
18 - Geoplex Field Devel- opment & Expansion (Site 4)			20.0(20.0)
20 - Direct Organic Cycle Field Expansion (Site 5)			3.0(3.0)

R-06 Reinjections and Fluid Flow Technology

This project, perhaps more than any other, is the most critical from the standpoint of resource success. The five-year A Budget project provides the basic laboratory and field demonstration of heat flow, reinjection, continuous field pressurizing and volume regulation, and energy extraction for the circulating water loops at Valles Caldera and Marysville. Further, the project constructs the loops used in project R-08 for process development of fluid and equipment clean-up. The B Budget researches fluid and equipment operating characteristics for the alternative water cycle and greatly expands the scale of the field circulation tests. Further, the B Budget provides more comprehensive laboratory testing prior to field testing. The clean-up methods engineered in this project are applied in project R-08. The tasks and budgets are summarized in Table 37.

TABLE 37. Summary of Recommended Budgets for Reinjection and Fluid Flow Technology Project for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-06 Reinjection and Fluid Flow Technology</u>	<u>4.1 (4.1)</u>	<u>7.4 (7.4)</u>	<u>7.4 (7.4)</u>
01 - Reinjection Technology	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
02 - Fluid Flow Studies	2.4 (2.4)	3.0 (3.0)	3.0 (3.0)
05 - Heat Extraction Experimental Design	0.2 (0.2)	0.3 (0.3)	0.3 (0.3)
06 - Heat Extraction Experiment	1.4 (1.4)	2.0 (2.0)	2.0 (2.0)
08 - In Situ Pressurized Water Circulation Studies	-	1.0 (1.0)	1.0 (1.0)
10 - In Situ Steam Cycle Circulation Studies	-	1.0 (1.0)	1.0 (1.0)

R-07 Power Generation Cycles

This project performs analytical studies, along with correlation of field and laboratory test data, to provide the information required to

optimize and select the power generation cycles for the various hot rock geothermal sites. The five-year A Budget provides only limited analyses to insure that the circulation methods (engineering heat transport loops) selected, and field expansion plans for Valles Caldera (assumed to be a binary fluid cycle) and Marysville (assumed to be a binary water/steam or direct steam cycle), correspond to the projected power plant needs for these sites. Cycle improvement studies are conducted on a limited basis. The ten-year program completes the cycle and field optimization programs for both sites. The B Budget greatly accelerates and expands the project scope for Marysville and Valles Caldera along with adding tasks to analyze, optimize, and select cycles for (1) the alternative water cycle, (2) the end-of-life (EOL) organic cycle, and (3) the direct organic cycle. The C Budget adds the Geoplex plant and reservoir cycle analysis and optimization. The project and task budget summary is shown in Table 38.

TABLE 38. Summary of Recommended Budgets for Power Generation Cycles Project for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-07 Power Generation Cycles</u>	<u>0.2 (0.2)</u>	<u>1.7 (1.7)</u>	<u>1.9 (1.9)</u>
01 - Application Analyses	0.08 (0.08)	0.3 (0.3)	0.3 (0.3)
02 - Plant Cycle Analyses and Selection	0.08 (0.08)	0.3 (0.3)	0.3 (0.3)
03 - Cycle Improvement Studies	0.05 (0.05)	0.2 (0.2)	0.2 (0.2)
05 - Alternative Steam Cycle Design	-	0.3 (0.3)	0.3 (0.3)
07 - Organic Binary Fluid Cycle EOL Plant	-	0.3 (0.3)	0.3 (0.3)
09 - Direct Cycle Organic Plant Analyses	-	0.3 (0.3)	0.3 (0.3)
13 - Geoplex Plant Analyses	-	-	0.2 (0.2)

R-08 Thermochemistry

Table 39 provides an outline of the tasks and budgets for the Thermochemistry project. This project provides the basic laboratory and field development demonstration for fluid and equipment cleanup processes of the circulating water loops (at Marysville and Valles Caldera, A Budget). The B Budget greatly expands and somewhat accelerates the water and steam clean-up research as well as provides research for the direct organic cycle circulating fluid. The C Budget addresses the research required for the Geoplex process and generating equipment.

The success of this thermochemistry project is absolutely essential to the success of the hot dry rock plant geothermal generation concept. The fluid and equipment (the equipment is tested in project R-09) must be fully compatible for power generation and fluid and energy transport so that reliability can be demonstrated for equipment operation. The likelihood of high levels of impurities, particularly silica compounds, in both circulating water and steam will require that extensive and research testing programs be successfully executed in the first five years of the project. The project task and budget summary follows in the next table.

TABLE 39. Summary of Recommended Budgets for Thermochemistry Project for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-08 Thermochemistry</u>	<u>2.0 (2.0)</u>	<u>5.8 (5.8)</u>	<u>6.3 (6.3)</u>
01 - Analyses & Field Tests	0.4 (0.4)	0.8 (0.8)	0.8 (0.8)
02 - Fluid Cleanup and Treatment	0.1 (0.1)	0.8 (0.8)	0.8 (0.8)
03 - Laboratory and Field Tests - Water	0.3 (0.3)	0.7 (0.7)	0.7 (0.7)
05 - Fluid Cleanup and Treatment - Steam	0.6 (0.6)	1.0 (1.0)	1.0 (1.0)
06 - Laboratory and Field Tests - Steam	0.6 (0.6)	1.0 (1.0)	1.0 (1.0)

08 - Organic Working Fluid Lab Circulation Tests	-	0.5 (0.5)	0.5 (0.5)
09 - Organic Working Fluid In Situ Circulation Studies	-	1.0 (1.0)	1.0 (1.0)
11 - Geoplex Circulating Fluid Applications Studies	-	-	0.5 (0.5)

R-09 Equipment Design, Fabrication and Test

The selection of the cycle for each site dictates where the emphasis should be placed in this project. The (1) pressurized cycle using binary water/steam has the least development problems. The (2) binary fluid (organic) cycle has essentially the same primary fluid-side research requirements. The (3) direct steam cycle may have the most difficult fluid clean-up and machinery design problems. The research tasks which address these specific problems are described in detail in the task sheets. The R-09 project, A Budget performs research for all three cycles in the ten-year plan but is limited to the (1)* and (2) cycles in the five-year plan due to the (presumed) relatively easier and less expensive research route. The B Budget accelerates and expands research into equipment for all three cycles as well as the relocatable plants including the EOL (organic) plant equipment. The direct cycle organic plant equipment is also researched under the B Budget. The C Budget funds research engineering and testing of the Geoplex equipment. The R-09 project provides proof of operation for all critical components prior to procurement for the pilot generating plants. Table 40 summarizes the budget tasks for the project.

*The binary organic (organic side) plant is to be developed under the hot water program.

TABLE 40. Summary of Recommended Budgets for Equipment Design, Fabricate and Test Project for the Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-09 Equipment Design, Fabrication and Test</u>	<u>3.1 (7.0)</u>	<u>8.6 (11.5)</u>	<u>9.6 (12.5)</u>
01 - Critical Component	1.0 (1.5)	1.8 (1.8)	1.8 (1.8)
02 - Test Equipment Field Operation - Water	0.7 (1.0)	1.3 (1.3)	1.3 (1.3)
03 - Pressurized Cycle Prototype	0 (1.2)	0.4 (1.6)	0.4 (1.6)
05 - Test Equipment Field Operation - Steam	0.7 (1.5)	1.3 (1.8)	1.3 (1.8)
06 - Direct Cycle Prototype	0 (1.2)	0.4 (1.6)	0.4 (1.6)
08 - Reinjection Equipment Design and Prototype Procurement	0.6 (0.6)	0.9 (0.9)	0.9 (0.9)
10 - Relocatable Plant and Component Design and Testing	-	1.0 (1.0)	1.0 (1.0)
12 - Direct Cycle Organic Component Design and Testing Lab & Field Tests	-	1.5 (1.5)	1.5 (1.5)
14 - Proof of Operation, Geoplex Systems	-	-	1.0 (1.0)

R-10 Pilot Plant Design

This task provides the designs for the pilot generating plants. The A Budget designs the Marysville and Valles Caldera plants; the B Budget accelerates these tasks and provides the alternative water cycle and EOL organic plant designs. The C Budget adds the Geoplex and direct cycle organic plant designs. Additionally, the A Budget provides a scope design for a 100-200 MWe demonstration commercial plant design which may also be used for the Geoplex plant depending upon the outcome of the development programs. The majority of the design work can be accomplished in the five-year program under the B Budget. Design work is not funded in the five-year A Budget. Project R-10 is summarized in Table 41.

TABLE 41. Summary of Recommended Budgets for Pilot Plant Design for Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-10 Pilot Plant Design</u>	<u>0 (2.2)</u>	<u>1.8 (3.3)</u>	<u>3.9 (5.9)</u>
01 - Valles Caldera, POCE- Power Generation	0 (0.6)	0.7 (0.7)	0.7 (0.7)
02 - Marysville, POCE- Power Generation	0 (0.6)	0.5 (0.7)	0.7 (0.7)
04 - Base Pilot Plant Design	0 (1.0)	0 (1.0)	0 (1.0)
06 - Alternative Water Cycle Plant Design, POCE - Power Generation (Site 3)	-	0 (0.2)	0 (0.2)
08 - EOL Organic Cycle Plant Design	-	0.5 (0.6)	0.5 (0.6)
11 - Geoplex	-	-	1.5 (2.0)
13 - Direct Organic Cycle Plant	-	-	0.6 (0.6)

R-11 Pilot Plant Construction

This task provides the construction funds for the POCE pilot plants. The task sheets provide information as to the construction schedule detail; the POCE plant startup sequences are shown in Figures 14-16. Table 42 outlines the project tasks and budgets.

TABLE 42. Summary of Recommended Budgets for Pilot Plant Construction for Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-11 Pilot Plant Construction</u>	<u>0 (12.0)</u>	<u>1.8 (21.0)</u>	<u>3.8 (111.0)</u>
01 - Valles Caldera Demonstration Plant	0 (4.0)	1.65 (4.5)	1.65 (4.5)
02 - Marysville Demonstration Plant	0 (8.0)	0.15 (8.5)	0.15 (8.5)
04 - Alternative Water Cycle Plant	-	0 (8.0)	0 (8.0)
06 - Geoplex	-	-	0 (80.0)
08 - Direct Cycle Organic Plant	-	-	0.20 (10.0)

R-12 Pilot Plant Operation

This task provides the startup, operating, and maintenance funds for the first 36 months of each plant's operation. After this 36-month period it is assumed that utilities will take over operation of the POCE plants. Table 43 provides the budget for operating funds. Figures 14-16 show operating sequences for the five generating plants.

TABLE 43. Summary of Recommended Budgets for Pilot Plant Operation for Hot Rock Resource
Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-12 Pilot Plant Operation</u>	<u>0 (5.0)</u>	<u>0 (7.5)</u>	<u>0 (15.0)</u>
01 - Marysville	0 (2.5)	0 (2.5)	0 (2.5)
03 - Valles Caldera	0 (2.5)	0 (2.5)	0 (2.5)
05 - Alternative Water Cycle Pilot Plant	-	0 (2.5)	0 (2.5)
07 - Geoplex	-	-	0 (5.0)
09 - Direct Cycle Organic Plant	-	-	0 (2.5)

R-13 Supporting Research

This project provides funding for major, but not critical, research and engineering programs. Critical research items are funded under the various projects. There is no funding for supporting research in the five-year A Budget. The ten-year program provides Rock-Water Chemistry and Propping research. The B Budget moves these two tasks into the first five years as well as funds a proprietary fracturing program, a deep well pump program, and expands the rock-water chemistry task. Additional propping research is funded in the R-05 project. Table 44 summarizes the supporting research project.

TABLE 44. Summary of Recommended Budgets Supporting Research for Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-13 Supporting Research</u>	<u>0 (0.7)</u>	<u>8.3 (8.7)</u>	<u>8.3 (8.7)</u>
01 - Rock-Water Chemistry	0 (0.4)	1.4 (1.8)	1.4 (1.8)
03 - Propping Research	0 (0.3)	0.3 (0.3)	0.3 (0.3)
05 - Heat Extraction and Fracturing	-	6.0 (6.0)	6.0 (6.0)
07 - Deep Well Pump Development	-	0.6 (0.6)	0.6 (0.6)

R-14 Environmental Studies

This task provides the environmental work specific to the Hot Dry Rock Resource. Basic geothermal environmental support work is performed under Subprogram E, Environmental-Social. The R-14 project funds impact studies for the POCE plants and field developments in the same sequence as the design and construction schedules discussed in R-10 and R-11. The five-year A Budget provides base line funding for Marysville and Valles Caldera and the ten-year A Budget completes these environmental studies and reports. The B and C Budgets complete the environmental reports for the three additional plants. A major area of environmental concern, induced seismicity, is addressed through base line studies in the A Budget and is considerably expanded in the B Budget. Table 45 summarizes the environmental project.

TABLE 45. Summary of Recommended Budgets for Environmental Studies for Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-14 Environmental Studies</u>	<u>0.2 (0.7)</u>	<u>0.8 (0.8)</u>	<u>1.4 (1.6)</u>
01 - Marysville Phase I	0.05 (0.05)	0.05 (0.05)	0.05 (0.05)
02 - Valles Caldera	0.05 (0.08)	0.08 (0.08)	0.08 (0.08)
03 - Seismic Evaluation Program	0.1 (0.4)	0.4 (0.4)	0.4 (0.4)
04 - Total Plant Impact Analyses	0 (0.2)	0.2 (0.2)	0.2 (0.2)

05 - Marysville Phase II	-	0.05 (0.05)	0.05 (0.05)
07 - Alternative Water Cycle Plant	-	0.1 (0.1)	0.1 (0.1)
09 - Geoplex Impact Statement	-	-	0.4 (0.5)
11 - Direct Organic Cycle Impact Statement	-	-	0.2 (0.3)

R-15 Plant Economics Analysis

This project provides the economic analyses for the cycles, plant designs, and power production. The five-year A Budget focuses on the initial two plants. The B Budget adds the third alternative water cycle plant analysis and expands and accelerates the Marysville and Valles Caldera analyses. The C Budget adds the Geoplex and direct organic plant economic analyses as well as provides a worldwide economic analysis of hot rock geothermal potential. The ten-year plan completes the analytical studies. The project will use the data generated for design decisions as well as enabling utilities and sponsoring agencies to determine the commercial characteristics of the resource. Table 46 summarizes the Plant Economics project.

TABLE 46. Summary of Recommended Budgets for Power Economics Analysis for Hot Rock Resource
Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-15 Power Economics Analysis</u>	<u>0.1 (0.3)</u>	<u>0.2 (0.3)</u>	<u>0.5 (0.6)</u>
01 - Economics Analysis	0.1 (0.3)	0.2 (0.3)	0.3 (0.4)
03 - Global Power Economics	-	-	0.2 (0.2)

R-16 Multiple Use of Resource

The multiple use project focuses primarily on mineral recovery from the geothermal field. It is not funded in the A Budget five-year plan. Basic laboratory and field mineral recovery research is conducted in the second five years. The B Budget provides operating mineral recovery pilot

operations at two sites and the C Budget provides a full-scale operating pilot plant within the first five years. Table 47 summarizes the R-16 project tasks and budgets. The project funds could be used for other multiple use applications as they develop.

TABLE 47. Summary of Recommended Budgets for Multiple Use of Resource for Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-16 Multiple Use of Resource</u>	<u>0 (0.2)</u>	<u>1.2 (1.2)</u>	<u>1.5 (1.5)</u>
01 - Mineral Recovery	0 (0.2)	1.2 (1.2)	1.2 (1.2)
03 - Mineral Recovery - Expanded Program	-	-	0.3 (0.3)

R-17 Utilization Project

This project provides a variety of services to the hot dry rock program. The project is not funded in the A Budget. The B and C Budgets provide (respectively) moderate and expanded information programs to energy companies, utilities, equipment suppliers, and the public. The project develops strategies for the most productive use of the resource. The project will provide intelligence and procedures for cooperatively sponsored programs and generating plants. The budgets are listed in Table 48 for this project.

TABLE 48. Summary of Recommended Budgets for Utilization Project for Hot Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-17 Utilization Project</u>	<u>0</u>	<u>0.4 (0.4)</u>	<u>1.0 (1.0)</u>
01 - Technology Transfer to Industry	0	0.2 (0.2)	0.4 (0.4)
03 - Productivity Analyses	0	0.1 (0.1)	0.2 (0.2)
05 - Industry/Government Cooperative Programs	0	0.1 (0.1)	0.4 (0.4)

Budget Summary

Table 49 provides a complete listing of all projects and tasks for the A, B and C Budgets, five- and ten-year plans, for the Hot Dry Rock Resource.

Schedules and Milestones

The critical path(s) for POCE's for the Hot Dry Rock Resource power generation are different depending on the cycle(s) selected, i.e., pressurized water/organic secondary, boiling direct, and/or pressurized water/steam secondary. The reader should refer to the State-of-the-Art and Problems sections preceding this section. It may be seen that hydrofracturing, followed by circulating loops, demonstrates only limited thermal extraction capabilities; the majority of the fluid-materials-machinery interactions are not solved without research programs focused on solving the specific critical components and process problems. Figures 14-16 provide sequenced schedules for the major tasks for the five- and ten-year A, B and C Budgets. The task sheets provide the detail for each research and engineering program.

The critical paths for the POCE circulating engineering loops and the POCE pilot generating plants can be traced on Figures 14-16. Basically, the A Budget yields a minimum program for engineering loops at Valles Caldera and Marysville in five years, and pilot generating plants at these sites in ten years. The B Budget somewhat accelerates these plants, adds a third alternative cycle plant, and greatly expands the research, engineering, and ancillary projects. The C Budget adds two advanced plants and further expands the research, engineering and ancillary programs. Both the B and C Budgets increase considerably the likelihood that the POCE's will be accomplished as predicted.

TABLE 49. Summary of Recommended Project and Task Budgets for Hot Dry Rock Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-00 Scoping and Planning</u>	<u>0.3(0.3)</u>	<u>0.9(0.9)</u>	<u>1.1(1.1)</u>
01 - Exploration	0	0	0
02 - Assessment	0.02(0.02)	0.05(0.05)	0.05(0.05)
03 - Reservoir Develop. - Modeling	0.01(0.01)	0.03(0.03)	0.03(0.03)
05 - Reservoir Develop. - Fracturing & Simulation	0.02(0.02)	0.07(0.07)	0.07(0.07)
06 - Reinjection & Fluid Flow Tech.	0.05(0.05)	0.1(0.1)	0.1(0.1)
07 - Power Generation Cycles	0.07(0.07)	0.2(0.2)	0.2(0.2)
08 - Thermochemistry	0.05(0.05)	0.1(0.1)	0.1(0.1)
09 - Equipment Design, Fabrication & Test	0.02(0.02)	0.06(0.06)	0.06(0.06)
10 - Pilot Plant Design	0.02(0.02)	0.04(0.04)	0.04(0.04)
11 - Pilot Plant Construc.	0	0	0
12 - Pilot Plant Operation	0	0.02(0.02)	0.02(0.02)
13 - Supporting Research	0.01(0.01)	0.02(0.02)	0.02(0.02)
14 - Environmental Studies	0.01(0.01)	0.02(0.02)	0.02(0.02)
15 - Power Economics Anal.	0	0	0
16 - Multiple Use of Resource	0	0	0
17 - Utilization Project	0.005(0.005)	0.02(0.02)	0.02(0.02)
19 - Site Selection & Eval.		0.05(0.05)	0.05(0.05)
21 - Alternate Cycle Eval.		0.05(0.05)	0.05(0.05)
23 - Alternate & Expanded Plant Designs		0.07(0.07)	0.07(0.07)
25 - Scoping Study, Geoplex			0.1(0.1)
27 - Direct Organic Cycle Plant Study			0.1(0.1)

TABLE 49 (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-02 Assessment</u>	<u>2.1(2.1)</u>	<u>15.1(15.1)</u>	<u>16.5(16.5)</u>
01 - Field Test - Valles Caldera	0.8(0.8)	0.8(0.8)	0.8(0.8)
02 - Field Test - Marysville	0.9(0.9)	0.9(0.9)	0.9(0.9)
03 - Assessment Methods	0.4(0.4)	1.4(1.4)	1.4(1.4)
05 - Resource Exploration & Prospecting		12.0(12.0)	12.0(12.0)
06 - Geoplex Survey & Selection			1.0(1.0)
08 - Direct Cycle Organic Site Selection			0.4(0.4)
<u>R-03 Reservoir Develop- ment - Modeling</u>	<u>0.2(0.2)</u>	<u>0.4(0.4)</u>	<u>0.4(0.4)</u>
01 - Modeling	0.2(0.2)	0.4(0.4)	0.4(0.4)
<u>R-05 Reservoir Develop.- Fracturing & Stimulation</u>	<u>5.0(7.0)</u>	<u>13.8(16.0)</u>	<u>36.8(39.0)</u>
01 - Field Test Frac- turing Studies Valles Caldera	2.0(2.0)	2.0(2.0)	2.0(2.0)
02 - Field Test Frac- turing Studies Marysville	1.0(1.0)	1.0(1.0)	1.0(1.0)
03 - Field Expansion Programs	1.2(3.3)	3.2(3.3)	3.2(3.3)
05 - High Explosive Selection & Application Design	0.1(0.1)	0.1(0.1)	0.1(0.1)

TABLE 49. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
06 - High Explosive Application	0.2(0.2)	0.2(0.2)	0.2(0.2)
07 - High Explosive Field Tests	0.4(0.4)	0.4(0.4)	0.4(0.4)
09 - Advanced Stimulation Technology Updating	0.005(0.006)	0.005(0.006)	0.005(0.006)
11 - Site 3 Development, Fracturing, & Fluid & Heat Flow		3.0(3.0)	3.0(3.0)
12 - Production Site - Field Expansion Program		1.0(3.0)	1.0(3.0)
14 - High Explosives Applications Testing		2.0(2.0)	2.0(2.0)
16 - High Explosives Engineering for Special Applications		1.0(1.0)	1.0(1.0)
18 - Geoplex Field Development & Expansion (Site 4)			20.0(20.0)
20 - Direct Organic Cycle Field Expansion (Site 5)			3.0(3.0)
<u>R-06 Reinjection & Fluid Flow Technology</u>	<u>4.1(4.1)</u>	<u>7.4(7.4)</u>	<u>7.4(7.4)</u>
01 - Reinjection Tech.	0.1(0.1)	0.1(0.1)	0.1(0.1)
03 - Fluid Flow Studies	2.4(2.4)	3.0(3.0)	3.0(3.0)
05 - Heat Extraction Experimental Des.	0.2(0.2)	0.3(0.3)	0.3(0.3)
06 - Heat Extraction Experiment	1.4(1.4)	2.0(2.0)	2.0(2.0)

TABLE 49. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
08 - In situ Pressur- ized Water Circulation Studies		1.0(1.0)	1.0(1.0)
10 - In situ Steam Cycle Circulation Studies		1.0(1.0)	1.0(1.0)
<u>R-07 Power Generation Cycles</u>	<u>0.2(0.2)</u>	<u>1.7(1.7)</u>	<u>1.9(1.9)</u>
01 - Application Analyses	0.08(0.08)	0.3(0.3)	0.3(0.3)
02 - Plant Cycle Analyses & Selection	0.08(0.08)	0.3(0.3)	0.3(0.3)
03 - Cycle Improve- ment Studies	0.05(0.05)	0.2(0.2)	0.2(0.2)
05 - Alternative Steam Cycle Design		0.3(0.3)	0.3(0.3)
07 - Organic Binary Fluid Cycle EOL Plant		0.3(0.3)	0.3(0.3)
09 - Direct Cycle Organic Plant Analyses		0.3(0.3)	0.3(0.3)
13 - Geoplex Plant Analyses			0.2(0.2)
<u>R-08 Thermochemistry</u>	<u>2.0(2.0)</u>	<u>5.8(5.8)</u>	<u>6.3(6.3)</u>
01 - Analyses & Field Tests	0.4(0.4)	0.8(0.8)	0.8(0.8)
02 - Fluid Cleanup & Treatment	0.1(0.1)	0.8(0.8)	0.8(0.8)
03 - Laboratory & Field Tests-Water	0.3(0.3)	0.7(0.7)	0.7(0.7)
05 - Fluid Cleanup & Treatment-Steam	0.6(0.6)	1.0(1.0)	1.0(1.0)

TABLE 49. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
06 - Laboratory & Field Tests-Steam	0.6(0.6)	1.0(1.0)	1.0(1.0)
08 - Organic Working Fluid Lab Circulation Tests		0.5(0.5)	0.5(0.5)
09 - Organic Working Fluid In situ Circulation Studies		1.0(1.0)	1.0(1.0)
11 - Geoplex Circulating Fluid Applications Studies			0.5(.5)
<u>R-09 Equipment Design, Fabrication & Test</u>	<u>3.1(7.0)</u>	<u>8.6(11.5)</u>	<u>9.6(12.5)</u>
01 - Critical Component	1.0(1.5)	1.8(1.8)	1.8(1.8)
02 - Test Equipment Field Operation-Water	0.7(1.0)	1.3(1.3)	1.3(1.3)
03 - Pressurized Cycle Prototype	0 (1.2)	0.4(1.6)	0.4(1.6)
05 - Test Equipment Field Operation-Steam	0.7(1.5)	1.3(1.8)	1.3(1.8)
06 - Direct Cycle Prototype	0 (1.2)	0.4(1.6)	0.4(1.6)
08 - Reinjection Equipment Design and Prototype Procurement	0.6(0.6)	0.9(0.9)	0.9(0.9)
10 - Relocatable Plant & Component Design and Testing		1.0(1.0)	1.0(1.0)
12 - Direct Cycle Organic Component Design & Testing Lab and Field Tests		1.5(1.5)	1.5(1.5)
14 - Proof of Operation, Geoplex Systems			1.0(1.0)

TABLE 49. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-10 Pilot Plant Design</u>	<u>0(2.2)</u>	<u>1.8(3.3)</u>	<u>3.9(5.9)</u>
01 - Valles Caldera, POCE-Power Generation	0(0.6)	0.7(0.7)	0.7(0.7)
02 - Marysville, POCE- Power Generation	0(0.6)	0.5(0.7)	0.7(0.7)
04 - Base Pilot Plant Design	0(1.0)	0 (1.0)	0 (1.0)
06 - Alternative Water Cycle Plant Design POCE-Power Genera- tion (Site 3)	0	0 (0.2)	0 (0.2)
08 - EOL Organic Cycle Plant Design		0.5(0.6)	0.5(0.6)
11 - Geoplex			1.5(2.0)
13 - Direct Organic Cycle Plant			0.6(0.6)
 <u>R-11 Pilot Plant Construc.</u>	 <u>0(12.0)</u>	 <u>1.8(21.0)</u>	 <u>3.8(111.0)</u>
01 - Valles Caldera Demonstration Plant	0 (4.0)	1.65(4.5)	1.65 (4.5)
02 - Marysville Demon- stration Plant	0 (8.0)	0.15(8.5)	0.15 (8.5)
04 - Alternative Water Cycle Plant		0 (8.0)	0 (8.0)
06 - Geoplex			0 (80.0)
08 - Direct Cycle Organic Plant			0.20(10.0)

TABLE 49. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-12 Pilot Plant Operation</u>	<u>0 (5.0)</u>	<u>0 (7.5)</u>	<u>0 (15.0)</u>
01 - Marysville	0 (2.5)	0 (2.5)	0 (2.5)
03 - Valles Caldera	0 (2.5)	0 (2.5)	0 (2.5)
05 - Alternative Water Cycle Pilot Plant		0 (2.5)	0 (2.5)
07 - Geoplex			0 (5.0)
09 - Direct Cycle Organic Plant			0 (2.5)
<u>R-13 Supporting Research</u>	<u>0 (0.7)</u>	<u>8.3(8.7)</u>	<u>8.3(8.7)</u>
01 - Rock-Water Chemistry	0 (0.4)	1.4(1.8)	1.4(1.8)
03 - Propping Research	0 (0.3)	0.3(0.3)	0.3(0.3)
05 - Heat Extraction & Fracturing		6.0(6.0)	6.0(6.0)
07 - Deep Well Pump Development		0.6(0.6)	0.6(0.6)
<u>R-14 Environmental Studies</u>	<u>0.2 (0.7)</u>	<u>0.8(0.8)</u>	<u>1.4(1.6)</u>
01 - Marysville Phase I	0.05(0.05)	0.05(0.05)	0.05(0.05)
02 - Valles Caldera	0.05(0.08)	0.08(0.08)	0.08(0.08)
03 - Seismic Evaluation Program	0.1 (0.4)	0.4(0.4)	0.4(0.4)
04 - Total Plant Impact Analyses	0 (0.2)	0.2(0.2)	0.2(0.2)
05 - Marysville Phase II		0.05(0.05)	0.05(0.05)
07 - Alternative Water Cycle Plant		0.1(0.1)	0.1(0.1)
09 - Geoplex Impact Statement			0.4(0.5)
11 - Direct Organic Cycle Impact Statement			0.2(0.3)

TABLE 49. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>R-15 Power Economics Analysis</u>	<u>0.1(0.3)</u>	<u>0.2(0.3)</u>	<u>0.5(0.6)</u>
01 - Economics Analysis	0.1(0.3)	0.2(0.3)	0.3(0.4)
03 - Global Power Economics			0.2(0.2)
 <u>R-16 Multiple Use of Resource.</u>	 <u>0(.2)</u>	 <u>1.2(1.2)</u>	 <u>1.5(1.5)</u>
01 - Mineral Recovery	0(.2)	1.2(1.2)	1.2(1.2)
03 - Mineral Recovery - Expanded Program			0.3(0.3)
 <u>R-17 Utilization Project</u>	 <u>0</u>	 <u>0.4(0.4)</u>	 <u>1.0(1.0)</u>
01 - Technology Transfer to Industry	0	0.2(0.2)	0.4(0.4)
03 - Productivity Analyses	0	0.1(0.1)	0.2(0.2)
05 - Industry/Government Cooperative Programs	0	0.1(0.1)	0.4(0.4)

FIGURE 14. Hot Dry Rock Geothermal Power - A Budget (Fiscal Year)

FIGURE 15. Hot Dry Rock Geothermal Power - B Budget (Fiscal Year)

FIGURE 15. (continued)

FIGURE 16. Hot Dry Rock Geothermal Power - C Budget (Fiscal Year)

FIGURE 16. (continued)

D. BRINE

Geothermal brine is defined for this planning study as all geothermal fluids with a total dissolved solids content greater than 30,000 parts per million (ppm). A level of 30,000 ppm total dissolved solids corresponds to a salinity of approximately three percent in typical geothermal fluid. Salinity rather than total dissolved solids content is generally used throughout this report to describe concentration, although the level of dissolved solids is a more precise description. The preference for salinity level is due to reasons of clarity and convenience. The descriptive term "hypersaline" is found in the technical literature when strong brine concentrations are discussed. The term is used in this report in reference to brine concentrations greater than approximately 20 percent.

Specification of a demarcation point to differentiate between the hot water and brine resources is based on the fact that sufficient differences exist to justify separate consideration for development purposes. Technical literature pertaining to geothermal resources generally either classifies brine apart from the hot water resource or treats brine as a special case within the hot water resource. The consensus of the study team on this project was that the development of hot water resources with a salinity greater than two or three percent would follow a different path than the development of hot water resources with less or no salinity.

No convenient break point for distinguishing between brine and hot water is apparent from the literature. Some authors consider a geothermal fluid to be brine if the salinity is 0.5 percent, while others classify everything as hot water. Saline geothermal fluids located to date have proven to be of less than three percent salinity, with the notable exception of the hypersaline brines of the Imperial Valley of California. Therefore, a lower limit of three percent salinity is a good division point, based on known reservoirs, to distinguish between hot water and brine.

The choice of three percent salinity as the demarcation between hot water and brine is further justified from a fluid chemistry standpoint. Chemical compounds leached from minerals in the reservoir formation such as silicates and carbonates are potentially more troublesome to resource

development than chloride compounds at concentrations below two or three percent. However, at salinities greater than two or three percent the problems associated with handling the preponderance of salts becomes dominant in resource development.

The geothermal brines assayed to date from reservoirs in the Imperial Valley are unlike seawater in composition. The comparative ratio of constituents show the geothermal brines to be enriched in certain elements such as potassium, calcium, lithium, iron, manganese, lead and zinc due to leaching from minerals in reservoir formations.⁽¹⁾ Thus, brines offer the possibility of "mining" the spent liquid following conversion of the heat to electricity. The feasibility of chemical byproduct recovery, however, is uncertain and will have to be considered on an individual reservoir basis.

Location

The major known brine reservoir of commercial potential within the United States is located at the southeastern end of the Salton Sea in the Imperial Valley. The area was of commercial interest as early as the 1920's but the first deep well flowing brine was not drilled until 1957.⁽²⁾ More than a dozen wells have been drilled since that time and most have resulted in successful production. The temperature of the reservoir fluids exceeds 300°C at depth in some wells and salinities range up to about 25 percent, which classifies the reservoir as hypersaline. A reasonable probability exists that further high temperature brine reservoirs will be located in the lower Imperial Valley, although the salinity levels apparently decrease in reservoirs south of the Salton Sea field. One field being developed in the lower Imperial Valley just across the Mexican border by the Federal Commission of Electricity of Mexico is producing geothermal fluids with a salinity of approximately two percent. Recent wells drilled by the Bureau

(1) Helgeson, H.C. "Geologic and Thermodynamic Characteristics of the Salton Sea Geothermal System", American Journal of Science, Vol. 266, pp. 129-166, March 1968.

(2) Ibid.

of Reclamation just north of the border near Holtville also indicate reservoir salinities below two percent.

It has been suggested that geothermal brines may lie beneath vapor-dominated or dry steam fields.⁽¹⁾ Verification of the presence of brines awaits deep drilling of these fields, but such a discovery would certainly spur efforts toward development of underground cavities to serve as flashing chambers. If the feasibility of flashing brines underground could be demonstrated, most of the major engineering problems of electric power generation from the resource would be overcome.

Overall estimates of the location of geothermal reservoirs in the coterminous 48 states indicate that the majority of the resources will be located in the western states. There is little basis for assuming that most of the brine reservoirs will not be found there also.

Value of Resource

Only one major brine reservoir with proven commercial potential has been located within the United States. The reservoir lies along the southeastern edge of the Salton Sea in the Imperial Valley. The reservoir occupies an area of at least 12 square miles and is conservatively estimated to contain 10^{15} kilocalories of heat in the brine.⁽²⁾ Using even the most conservative factors for conversion of this energy in the underground fluid to electrical energy, this reservoir has a significant commercial potential (about 800 MW centuries).

The BNW study team made an estimate that approximately 10 percent of the liquid-dominated systems discovered in the foreseeable future would consist of brine. An estimate of the future brine resource was obtained by applying the 10 percent factor to recent estimates by the Bechtel Corporation

(1) Geothermal Energy, Paul Kruger and Carel Otte, editors. Stanford University Press, Stanford, CA., p. 82, 1973.

(2) Helgeson, H.C. "Geologic and Thermodynamic Characteristics of the Salton Sea Geothermal System," American Journal of Science, Vol. 266, pp. 129-166, March 1968.

of identified liquid-dominated resources in the future on a normal and crash development basis.⁽¹⁾ The Bechtel estimates of recoverable liquid-dominated resources are as follows:

	<u>1985 Normal</u>	<u>1985 Crash</u>	<u>2000 Normal</u>	<u>2000 Crash</u>
Identified Liquid-Dominated Resource (10^6 Mwt. yrs)	10	1000	50	1000

Applied to the brine resource the identified resource (10^6 Mwt. yr) is estimated to be:

	<u>1985 Normal</u>	<u>1985 Crash</u>	<u>2000 Normal</u>	<u>2000 Crash</u>
Identified Brine Resource (10^6 Mwt. yrs)	1	100	5	100

Problems

A major brine reservoir in the Imperial Valley was identified over 15 years ago and has been available for development by industry since that time. There has been commercial interest, but no electric power generation has yet resulted. The major impediments to commercial development of the brine resource have been associated with fluid chemistry and the resultant effects on fluid handling and power conversion equipment, uncertainties related to the feasibility of reinjection, and a lack of knowledge concerning the hydrothermal characteristics of the reservoirs. Further problems, less severe in nature, include a lack of capability to drill economically into the higher temperature reservoir formations and inadequate exploration and assessment techniques.

Scaling and corrosion of equipment in contact with the geothermal brine will undoubtedly be a continuing problem which can only be minimized rather than eliminated by improvements in materials or chemical treatment

(1) Carasso, M. A Technological Assessment of Geothermal Resource Development, Bechtel Corp., August 1975.

methods. Up to five million pounds of dissolved solids will be delivered to the surface each day from a single production well in a hypersaline reservoir.⁽¹⁾ The flow of brine required by a commercial-size power plant of 100-200 MW might therefore pass as much as one hundred million pounds of dissolved solids through the system daily. Scaling of equipment is potentially a more serious problem for equipment than corrosion because the known technological approaches to solving the problem are more limited.

The presence of hydroconvection cells within the reservoir structure would have significant effect on reservoir engineering practices. Convective cells are thought to exist in the geothermal reservoirs of the Imperial Valley.⁽²⁾ However, the presence and nature of these cells has yet to be verified. Drilling requirements for both production and reinjection wells will be significantly reduced if natural fluid flow within the reservoir can be utilized.

Reinjection appears to be the only viable alternative for disposal of the spent geothermal fluid in the United States. The liquid effluent from the wells at Cerro Prieto in Mexico is released on the surface rather than reinjected so no experience with reinjection is available from that commercial plant. Fluid chemistry problems associated with reinjecting the enormous quantities of dissolved solids (and perhaps some precipitated solids) contained in the brine after cooling have not yet been solved. Reinjection problems are expected to be considerably different for each new reservoir located. Therefore, many of the problems cannot even be worked on until the new reservoirs are located. Merely maintaining the solids in solution following cooling will not necessarily solve reinjection problems. Chemical reactions are likely between the fluid and the formation if the fluid is reinjected at a location different from the point of withdrawal.

(1) Helgeson, H.C. "Geologic and Thermodynamic Characteristics of the Salton Sea Geothermal System", American Journal of Science, Vol. 266, March 1968, pp. 129-166.

(2) Geothermal Resource Investigations-Developmental Concepts, USDI Bureau of Reclamation, January 1972, p. 33.

The limitations or inadequacies in drilling, exploration and assessment hamper development of the resource primarily from an economic rather than a technological standpoint. Reservoirs can be located, assessed and drilled with enough time and money. Future commercial development will require deeper holes into hotter reservoirs before the deep liquid-dominated resources can be utilized economically.

Development Strategy

The program for development of the brine resource is divided into 17 separate projects. A summary of funding for five and ten years at the A, B and C Budget levels is shown in Table 50. Other projects such as institutional considerations, environmental studies, exploration, and drilling development have been considered generically for all resource development programs and the funding levels are reflected elsewhere within this report. No funding is indicated under Project B-01, Exploration, as this program is considered generically for all resources.

The low level of funding relative to other resource subprograms, recommended for development of the brine resource is due to the following reasons:

- The potential for electrical production in the future ranks far below estimates for production from the hot/warm water and hot dry rock resources.
- Technological problems are not as likely to be solved over a short term to enable rapid development of the resource. The problems of the hot/warm water resource can be overcome more expeditiously.
- Significant technology transfer can be expected from developments in the more promising resources.
- Meaningful demonstration of the commercial viability of the brine resource is not likely within five years and could require over ten years.

The program development for the brine resource was planned over a 10-year period of time, beginning in Fiscal Year 1974. The primary emphasis at the lowest budget level (A Budget) within the first five years is

TABLE 50. Summary of Recommended Project Budgets
for Brine Resource Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>5.30 (24.73)</u>	<u>30.00 (52.54)</u>	<u>36.60 (78.62)</u>
B-00 Scoping and Planning	0.10 (0.10)	0.50 (0.50)	0.60 (0.60)
B-01 Exploration	0 (0)	0 (0)	0 (0)
B-02 Assessment	2.00 (5.00)	3.00 (7.40)	4.00 (10.60)
B-03 Reservoir Development-Modeling	0.10 (0.10)	0.40 (0.40)	0.40 (0.40)
B-04 Reservoir Development- Production Wells	0 (5.00)	3.00 (7.50)	4.00 (12.50)
B-05 Reservoir Development- Stimulation	0 (0)	1.30 (1.30)	1.30 (1.30)
B-06 Reinjection Technology	0.60 (0.60)	3.00 (3.00)	4.20 (4.20)
B-07 Power Generation Cycles	0 (0)	0.20 (0.38)	0.50 (0.50)
B-08 Thermochemistry	2.50 (2.50)	2.50 (2.50)	2.50 (2.50)
B-09 Equipment Design, Development and Test	0 (1.30)	3.10 (3.60)	4.70 (5.00)
B-10 Pilot Plant Design	0 (0.80)	0.80 (1.70)	0.80 (2.90)
B-11 Construction of Pilot Plants	0 (6.00)	6.00 (14.00)	6.00 (24.00)
B-12 Pilot Plant Operation	0 (1.70)	0 (2.40)	0 (3.60)
B-13 Supporting Research	0 (0)	3.00 (3.00)	3.00 (4.00)
B-14 Environmental Studies	0 (0.37)	0.50 (0.89)	1.10 (1.52)
B-15 Power Economics Analysis	0 (0.41)	0.20 (0.47)	0.40 (0.55)
B-16 Multiple Use of Resource	0 (0)	2.00 (2.00)	2.00 (2.50)
B-17 Utilization Plan	0 (0.85)	0.50 (1.50)	1.10 (1.95)

directed toward projects in which the technology is transferable to the development of other resources, such as reinjection technology and thermo-chemistry. During the second 5-year period, more emphasis is placed on the problems that tend to be unique to the brine resource. The funding at the middle budget level (B Budget) reflects an attempt to provide transferable technology within the first five years and also to accelerate the projects necessary to bring the resource to a meaningful demonstration stage. The highest budget level (C Budget) funding is directed more toward demonstrating commercial viability of the brine resource alone as the other major resource allocations appear sufficient for complete development within individual program funding.

A pilot plant cannot be constructed within the first five years at the funding level of the A Budget. However, provision is made for construction of a pilot plant during the second five years under the A Budget. Both of the higher budgets provide for pilot plant construction within the initial five years, although the probability of successful completion of the POCE pilot plants within this time frame is uncertain.

Projects

Descriptions and recommended funding levels for the individual projects and included tasks are summarized in the sections below. The project and task titles have been shortened for convenience in the tables. Complete titles and task descriptions are found in the individual task sheets in Appendix B. Table 68 at the end of the section is a summary of the recommended budgets for the entire brine resource.

B-00 Scoping and Planning

The Scoping and Planning Project is a Phase 0 study from which a coordinated plan of resource development will emerge. A complete survey of the present state-of-the-art, assessment of transferrable technology and a precise definition of problems will be accomplished. Individual tasks will be designed to provide a comprehensive plan before proceeding with subsequent related projects. The tasks within the Scoping and Planning

Project are specifically addressed to all of the subsequent projects. All tasks are expected to be completed within the initial four to nine months. Subsequent projects would begin only upon completion of the related task from Project B-00.

The restrictive allocation under the A Budget forces a limited Phase 0 study, restricted to only those projects likely to be funded in the first five years. If further funding allocations were to become available, all tasks within this project should be funded. Table 51 is a budget summary of Project B-00 for the three budget levels.

B-01 Exploration

Exploration was originally considered as a distinct project within each resource development program. As the study progressed, it became apparent that exploration (as defined in the Glossary) is more likely to be conducted in search of heat anomalies rather than the individual types of resources, *per se*. Exploration is included in a generic project elsewhere. Therefore, no funding is allocated to exploration within the brine resource development program.

B-02 Assessment

Assessment is also partially funded in a generic project for all resource types. However, it is felt that specific and detailed assessment is required within the brine resource development program to essentially pinpoint the reservoirs. A considerable expenditure is also felt to be necessary for detailed characterization of individual reservoirs. The project consists of five tasks. Only the first (Surface Mapping) does not require drilling into the reservoir formation. The remaining four tasks are devoted to characterizing the geothermal fluid and formation and flow characteristics. Fluid mass transport studies are considered vital to the reservoir assessment project; the presence and nature of convection cells is also important to other projects such as Reinjection Technology and all other reservoir development projects.

TABLE 51. Summary of Recommended Budgets for Scoping and Planning Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-00 Scoping and Planning</u>	<u>0.10 (0.10)</u>	<u>0.50 (0.05)</u>	<u>0.60 (0.60)</u>
01 - Exploration	0 (0)	0 (0)	0 (0)
02 - Assessment	0.02 (0.02)	0.03 (0.03)	0.03 (0.03)
03 - Reservoir Development- Modeling	0.01 (0.01)	0.02 (0.02)	0.02 (0.02)
04 - Reservoir Development- Production Wells	0 (0)	0.03 (0.03)	0.03 (0.03)
05 - Reservoir Development- Stimulation	0 (0)	0.01 (0.01)	0.04 (0.04)
06 - Reinjection Technology	0.02 (0.02)	0.03 (0.03)	0.03 (0.03)
07 - Power Generation Cycles	0 (0)	0.05 (0.05)	0.06 (0.06)
08 - Thermochemistry	0.04 (0.04)	0.06 (0.06)	0.07 (0.07)
09 - Equipment Design, Develop- ment and Test	0 (0)	0.05 (0.05)	0.06 (0.06)
10 - Pilot Plant Selection and Design	0 (0)	0.04 (0.04)	0.05 (0.05)
11 - Construction of Pilot Plants	0 (0)	0.02 (0.02)	0.02 (0.02)
12 - Pilot Plant Operation	0 (0)	0 (0)	0 (0)
13 - Supporting Research	0 (0)	0.05 (0.05)	0.07 (0.07)
14 - Environmental Studies	0.01 (0.01)	0.02 (0.02)	0.03 (0.03)
15 - Power Economic Analysis	0 (0)	0.04 (0.04)	0.04 (0.04)
16 - Multiple Use of Resource	0 (0)	0.03 (0.03)	0.03 (0.03)
17 - Utilization Plan	0 (0)	0.02 (0.02)	0.02 (0.02)

The Reservoir Assessment Project was allocated a relatively high funding level during the first five years at each budget level because the results of the assessment will be pertinent to other types of liquid-dominated systems. Test wells were planned into the second 5-year period at each budget level. The intent is that field experience will provide a much better background and capability for judgment of resource potential than would result from related efforts in the laboratory. Table 52 is a budget summary for Project B-02.

TABLE 52. Summary of Recommended Budgets for Assessment Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-02 Assessment</u>	<u>2.0 (5.0)</u>	<u>3.0 (7.4)</u>	<u>4.0 (10.6)</u>
01 - Surface Mapping	0.15 (0.45)	0.25 (0.6)	0.45 (0.9)
03 - Test Wells	1.0 (3.0)	1.4 (4.2)	1.8 (6.0)
05 - Fluid Characterization	0.2 (0.5)	0.3 (0.9)	0.3 (1.2)
07 - Characterization of Formations	0.15 (0.3)	0.25 (0.5)	0.25 (1.8)
09 - Mass Transport Studies	0.5 (0.75)	0.8 (1.2)	1.2 (1.8)

B-03 Reservoir Development-Modeling

Project B-03 consists of the single task of developing a three-dimensional hydrothermal model of a representative brine reservoir. A model will be required for sound reservoir engineering and production management. The location, spacing, depth, size, etc., of production and reinjection wells will ultimately be decided from the reservoir model. This project was felt necessary at all three budget levels and will best be carried out in the initial five years as early as practicable. The data input and demonstration of the model will essentially be provided within other projects. Table 53 is a budget summary for Project B-03.

TABLE 53. Summary of Recommended Budgets for Reservoir Development-Modeling Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-03 Reservoir Development - Modeling</u>	<u>0.1 (0.1)</u>	<u>0.4 (0.4)</u>	<u>0.4 (0.4)</u>
01 - Three-Dimensional Hydrothermal Model	0.1 (0.1)	0.4 (0.4)	0.4 (0.4)

B-04 Reservoir Development - Production Wells

Project B-04 consists of the single task of drilling and testing production and reinjection wells. The relative success of production and reinjection wells is based on performance over an extended period of time. However, a 10-year program necessitates compression of the desired time schedule for determining ultimate well life. The only available approach to demonstration of sustained reservoir production capability is to drill the wells for the pilot plants as early in the development program as possible following location of suitable sites. The wells can then be tested for a year or more before the pilot plants are constructed.

The A Budget brine resource allocation was not sufficient to provide production wells within the first five years of the program. The test wells are therefore scheduled for the initial period of the last five years. The B and C Budgets also have provision for production wells early in the second 5-year period, in addition to those funded in the first five years. The 5-year funding levels were not felt adequate to develop a sufficient number of production well sites. The production and reinjection well flow tests can be designed to demonstrate sustained production capability of a reservoir without installation of pilot plants. Table 54 is a budget summary for Project B-04.

TABLE 54. Summary of Recommended Budgets for Reservoir Development-Production Wells Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-04 Reservoir Development - Production Wells</u>	<u>0 (5.0)</u>	<u>3.0 (7.5)</u>	<u>4.0 (12.5)</u>
01 - Production and ReInjection Wells	0 (5.0)	3.0 (7.5)	4.0 (12.5)

B-05 Reservoir Development - Stimulation

The stimulation of brine reservoirs may not be necessary for increased production as adequate flow has been obtained from most wells drilled to date in the Imperial Valley. Stimulation of the reservoir to facilitate reinjection is funded separately in Project B-06. Stimulation is a major effort in the hot dry rock program and at least a portion of the technology developed is expected to be transferable to development of liquid-dominated resources. Stimulation experiments are therefore not recommended in the A Budget and receive relatively little attention in the B and C Budgets. The creation of an underground flashing chamber within the reservoir formation could solve many, if not most, of the subsequent equipment problems of corrosion and scaling. Although the practicability is not promising at this time, the majority of the funds allocated in the higher budgets are toward this end. Table 55 is a budget summary for Project B-05.

TABLE 55. Summary of Recommended Budgets for Reservoir Development-Stimulation Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-05 Reservoir Development - Stimulation</u>	<u>0 (0)</u>	<u>1.3 (1.3)</u>	<u>1.3 (1.3)</u>
01 - Stimulation Feasibility Study	0 (0)	0.05 (0.05)	0.05 (0.05)
02 - Tests of Stimulation Techniques	0 (0)	0.45 (0.45)	0.45 (0.45)
04 - Underground Cavity	0 (0)	0.8 (0.8)	0.8 (0.8)

B-06 ReInjection Technology

Development of reinjection technology is one of the most critical projects for the commercial development of the brine resource. The research and development requirements are unique to the brine resource, although many of the results may be applicable to other resources. The five tasks are directed primarily toward treating the geothermal fluid chemically before reinjection and also chemical treatment and mechanical stimulation of the reservoir structure. The stimulation techniques may also be applicable to extending the useful life of production wells (well work-over).

Countless billions of pounds of dissolved solids will be delivered to the surface over the life of the reservoir, and reinjection appears to be the only viable alternative for disposal of the spent fluid. The feasibility of reinjection may depend to a great extent on the presence of convective cells within the reservoir to redistribute the spent fluid within the reservoir. This project is, therefore, funded at all budget levels, although the brine program allocation at the lowest budget level does not permit extensive tests. The project is limited to the first five years at each level because of the importance to subsequent program development in other projects. Table 56 is a budget summary for Project B-06.

TABLE 56. Summary of Recommended Budgets for ReInjection Technology Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-06 ReInjection Technology</u>	<u>0.6 (0.6)</u>	<u>3.0 (3.0)</u>	<u>4.2 (4.2)</u>
01 - Chemical Treatment Methods	0.15 (0.15)	0.45 (0.45)	0.45 (0.45)
02 - Verification of Reinjection Techniques	0.4 (0.4)	1.1 (1.1)	1.1 (1.1)
04 - Alternative ReInjection Locations	0.05 (0.05)	0.75 (0.75)	1.2 (1.2)
06 - Mechanical Stimulation of Formation	-	0.7 (0.7)	1.0 (1.0)
08 - Chemical Treatment of Formation	-	-	0.45 (0.45)

B-07 Power Generation Cycles

The severe corrosiveness and scaling tendencies of geothermal brine on equipment can be minimized in an indirect cycle. Contact with the prime mover by the geothermal fluid is avoided. The prime movers (normally steam turbines) are especially sensitive to the fluid properties. Binary fluid cycles for power conversion may become necessary if indirect cycles are shown to be practical, particularly at lower reservoir temperatures. Development of improved heat exchangers and deep-well pump development are funded under Project B-09. There should be considerable technology transfer between this project and similar ones funded under the Hot and Warm Water subprograms. Flashing of steam from brines on the lower end of the salinity range for direct expansion through prime movers will likely remain the most economical method of power production if reinjection problems can be overcome. The power plant at Cerro Prieto in Mexico flashes steam from geothermal fluid of approximately two percent salinity. Corrosion and scaling would remain a problem in steam turbines and fluid handling components through which flash steam from brine passed. Therefore, funding is provided to evaluate and develop expansion devices other than turbines.

Brine reservoir temperatures can theoretically be higher than those of similar hot water systems. Reservoirs monitored in the Imperial Valley to date indicate that hypersaline reservoirs are indeed hotter (up to about 350°C) than hot water reservoirs in the same general area. Therefore, binary fluid cycles will have to be designed for higher temperature ranges.

No funding is recommended for development of power generation cycles within the restrictive A Budget. A very low level of funding is recommended in the 5- and 10-year higher budget levels toward development of power generation cycles because it is assumed that most of the required developments will be transferable from other resource development programs. Table 57 is a budget summary for Project B-07.

TABLE 57. Summary of Recommended Budgets for Power Generation Cycles Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-07 Power Generation Cycles</u>	<u>0 (0)</u>	<u>0.2 (0.38)</u>	<u>0.5 (0.5)</u>
01 - Evaluate Physical, Chemical and Thermo-dynamic Properties	-	0.04 (0.04)	0.04 (0.04)
03 - Evaluate Binary Fluid Systems	-	0.03 (0.05)	0.05 (0.05)
05 - Evaluate Systems Other Than Turbines	-	0.06 (0.08)	0.11 (0.11)
07 - Select Optimum Systems	-	0.02 (0.02)	0.03 (0.03)
09 - Develop New Binary Fluids	-	0 (0.06)	0.1 (0.1)
11 - Evaluate Nonconventional Methods	-	0.05 (0.07)	0.07 (0.07)
13 - Design Advanced Expansion Machines	-	0 (0.06)	0.1 (0.1)

B-08 Thermochemistry

The developments within the Thermochemistry Project are very basic to developments within other brine resource projects and will also apply to the other resource development efforts. The tasks are directed toward minimizing scaling and corrosion; they support considerable materials research. Basic mechanisms such as deposition kinetics must be completely understood before practical solutions of the scaling problem can be attempted.

This project is funded equally at all budget levels within the first five years because the results are felt to be of fundamental importance to subsequent development of the resource. Table 58 is a budget summary for Project B-08.

TABLE 58. Summary of Recommended Budgets for the Thermochemistry Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-08 Thermochemistry</u>	<u>2.5 (2.5)</u>	<u>2.5 (2.5)</u>	<u>2.5 (2.5)</u>
01 - Materials Research Tests	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)
03 - Corrosion, Erosion and Scaling Tests	0.4 (0.4)	0.4 (0.4)	0.4 (0.4)
05 - Deposition Kinetics Studies	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)
07 - Fluid Chemical Treatment Studies	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
09 - Cathodic Protection Systems	0.6 (0.6)	0.6 (0.6)	0.6 (0.6)
11 - Chemical Methods for Scale Removal	0.2 (0.2)	0.2 (0.2)	0.2 (0.2)

B-09 Equipment Design, Development and Test

Project B-09 is directed toward the eventual demonstration of the equipment deemed most critical to successful resource utilization. The majority of the tasks are devoted toward equipment used in an indirect cycle such as deep well pumps and heat exchangers. Development of equipment in the other resource programs will be partially transferable to the brine resource. However, the severe corrosion-scaling effects of the brine on equipment is expected to necessitate additional research.

The relatively high cost of equipment development precludes funding of tasks within the A Budget in the first five years; minimal effort is devoted to equipment development in the second five years. The B and C Budget efforts fall primarily within the first five years. The most severe time constraint on the development of equipment is the necessity to await the preliminary result of several earlier projects, such as Thermochemistry and Assessment. The equipment designer must be provided with an accurate set of design criteria before proceeding with the design. However, many project tasks will have to begin before sufficient data are available because of time limitations.

Tasks are recommended within this project to construct and operate a test bed facility. The facility could greatly shorten the overall time required for equipment development. However, inadequate funding at all budget levels in the first five years would preclude the facility under the brine resource development program. The availability of test bed facilities from other resource programs would be questionable. Thought should be given to establishing a national test bed facility for all geothermal resources. Table 59 is a budget summary for Project B-09.

TABLE 59. Summary of Recommended Budgets for Equipment Design, Development and Test Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-09 Equipment Design, Development and Test</u>	<u>0 (1.3)</u>	<u>3.1 (3.6)</u>	<u>4.7 (5.0)</u>
01 - Design and Construct Test Bed Facility	-	-	-
02 - Operate Test Bed Facility	-	-	-
04 - Design and Test Heat Exchanger (Conventional)	0 (0.4)	0.6 (0.6)	0.6 (0.6)
06 - Design and Test Reinjection Pumps	0 (0.2)	0.3 (0.3)	0.3 (0.3)
08 - Design and Test Binary Fluid Cycle Components	-	0.3 (0.6)	0.7 (0.7)
10 - Design and Test Equipment for the Removal of Non-condensable Gases	-	0.4 (0.4)	0.4 (0.4)
12 - Design and Test Deep Well Pump	0 (0.6)	1.0 (1.0)	2.0 (2.0)
14 - Design and Test Mechanical Scale Removal Devices	0 (0.1)	0.2 (0.2)	0.2 (0.2)
16 - Advanced Heat Exchanger Design and Test	-	0.3 (0.5)	0.5 (0.8)

B-10 Pilot Plant Design

The design of pilot plants will require input from practically every other project within the brine resource development program, which makes

timing very critical. Much of the design will be restricted to "state-of-the-art" for the first few years until the results of other projects become available. A total of three pilot plants would be designed within the ten year program at the three budget levels: one within the A Budget, two within the B Budget, and three within the C Budget. The pilot plants are described further in the next section and in the task sheets in the Appendix. No pilot plant design is recommended for the first five years of the A Budget due to limited funds. Table 60 is a budget summary for Project B-10.

TABLE 60. Summary of Recommended Budgets for Pilot Plant Design Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-10 Pilot Plant Design</u>	<u>0 (0.8)</u>	<u>0.8 (1.7)</u>	<u>0.8 (2.9)</u>
01 - "State-of-the-Art" Plant for Low Salinity Reservoir	0 (0.8)	0.8 (0.8)	0.8 (0.8)
03 - Plant for Hypersaline Reservoir	-	0 (0.9)	0 (0.9)
05 - Special Purpose Plant	-	-	0 (1.2)

B-11 Construction of Pilot Plants

Three pilot plants are recommended for final POCE demonstration of the brine resource: a "state-of-the-art" pilot plant for a low salinity reservoir, a pilot plant for a hypersaline reservoir, and a special purpose plant which is not directly associated with national energy needs or in competition with other energy sources. The "state-of-the-art" plant would probably be a direct cycle system using the best available materials for construction. It would also probably be limited to only flashed steam due to time restrictions. The plant is included as the best approach to a pilot plant demonstration within five years. The output would be in the 10-20 MW range. This plant is scheduled for completion within the first five years in the B and C Budgets and just after the fifth year in the A Budget.

A pilot plant for a hypersaline reservoir is improbable within the first five years because of the necessity for complex technological

development in several areas. This plant is funded in the second five years under the B and C Budgets.

The special purpose plant would be intended to demonstrate the potential for the brine geothermal resource to fulfill a regional need economically without regard to the economic viability of the overall brine resource. An example of such a plant would be a power plant that also provided a source of space heating for the remote native villages in areas of Alaska. The plant might also be one in which a combination of power production and chemical byproduct recovery was demonstrated for a reservoir with fluid enriched in specific minerals. Table 61 is a budget summary for Project B-11.

TABLE 61. Summary of Recommended Budgets for Construction of Pilot Plants Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-11 Construction of Pilot Plants</u>	<u>0 (6.0)</u>	<u>6.0 (14.0)</u>	<u>6.0 (24.0)</u>
01 - "State-of-the-Art" Plant for Low Salinity Reservoir	0 (6.0)	6.0 (6.0)	6.0 (6.0)
03 - Plant for Hypersaline Reservoir	-	0 (8.0)	0 (8.0)
05 - Special Purpose Plant	-	-	0 (10.0)

B-12 Pilot Plant Operation

This project provides funds for operating the three pilot plants designed and constructed in Projects B-10 and B-11. Operation of the pilot plants is in the second five years at all budget levels. The recommended operating time for the plants is three years. However, only the "state-of-the-art" plant under the B and C Budgets is expected to have a completion date early enough to provide the three years of operation within the 10-year program. Table 62 is a budget summary for Project B-12.

TABLE 62. Summary of Recommended Budgets for Pilot Plant Operation Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-12 Pilot Plant Operation</u>	<u>0 (1.7)</u>	<u>0 (2.4)</u>	<u>0 (3.6)</u>
01 - "State-of-the-Art" Plant for Low Salinity Reservoir	0 (1.7)	0 (2.0)	0 (2.0)
03 - Plant for Hypersaline Reservoir	-	0 (0.4)	0 (0.4)
05 - Special Purpose Plant	-	-	0 (1.2)

B-13 Supporting Research

Supporting research is considered to be development in areas where the required technology is available but is not economically attractive. Improvements in the technology of drilling production and reinjection wells is funded separately under the brine development program. This is because the much larger expenditure in the generic drilling development program would not likely be addressed to improvements in the economy of drilling a large number of holes in a restricted area. The other equipment development tasks are primarily directed toward reducing the cost or improving the performance of "state-of-the-art" equipment. High temperature monitoring instruments are presently inadequate for service in the hot, corrosive environment of the hypersaline fluids. Improvements are needed in the cost and performance of many types of instruments.

No supporting research projects were funded under the A Budget due to lack of funds. Funding at the B and C levels are within the first five years because the emphasis should be directed toward improvements that can be incorporated in the pilot plants. Table 63 is a budget summary for Project B-13.

TABLE 63. Summary of Recommended Budgets for Supporting Research Project for the Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-13 Supporting Research</u>	-	3.0 (3.0)	3.0 (4.0)
01 - Improved Techniques for Drilling Wells	-	0.9 (0.9)	0.9 (0.9)
03 - Design and Test of Fluid Handling Components	-	0.5 (0.5)	0.5 (0.5)
05 - Design and Test of Steam Flashing Units	-	0.3 (0.3)	0.3 (0.3)
07 - Design and Test of Steam Condensers	-	0.5 (0.5)	0.5 (0.5)
09 - Design and Test of Borehole Screens	-	0.2 (0.2)	0.2 (0.2)
11 - Develop High Temperature Monitoring Instruments	-	0.6 (0.6)	0.6 (1.6)

B-14 Environmental Studies

Environmental studies are included within a generic project that applies to all resources. The studies within the brine resource development are restricted to those unique to the brine resource. The project includes tasks to develop equipment that will reduce known effects on the environment such as the release of specific contaminants. Environmental surveys, monitoring and impact statements are also funded for the brine reservoirs selected for pilot plants.

Environmental studies are not funded in the first five years under the A Budget because no pilot plants will be constructed in that time. The budget for the second five years will require environmental site surveys and impact statements. The B and C Budget funds and recommended tasks are similar in the first and second 5-year period, except that the C Budget has provisions for an additional pilot plant. Table 64 is a budget summary for Project B-14.

TABLE 64. Summary of Recommended Budgets for Environmental Studies Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-14 Environmental Studies</u>	<u>0 (0.37)</u>	<u>0.5 (0.89)</u>	<u>1.1 (1.52)</u>
01 - Assess Potential Seismic Effects	0 (0.12)	0.05 (0.15)	0.15 (0.15)
03 - Develop Contaminant Removal Systems	-	0.14 (0.15)	0.5 (0.5)
05 - Environmental Surveys of Sites	0 (0.12)	0.06 (0.18)	0.11 (0.24)
07 - Environmental Monitoring	0 (0.03)	0 (0.06)	0 (0.09)
09 - Environmental Impact Statements	0 (0.1)	0.1 (0.2)	0.1 (0.3)
11 - Develop Noise Abatement Devices	-	0.15 (0.15)	0.24 (0.24)

B-15 Power Economic Analysis

An economic analysis is inherent in many of the tasks in other projects. The economic analyses within this project are oriented toward those which consider a reservoir or power conversion system as a whole rather than analysis of the feasibility of specific subsystem elements. The economic viability of the brine resource can best be demonstrated by taking the results of demonstrations from the brine resource development program and extrapolating these results to a commercial-size operation. The final POCE resource analysis is intended to fulfill this ultimate objective and is therefore scheduled for the end of the 10-year program.

The Power Economic Analysis Project will not be funded under the A Budget in the first five years. The tasks funded in the second five years would begin during the sixth year, except for the final POCE resource analysis. The funding under the B Budget is felt inadequate for the first five years, so the tasks would be extended into the second half of the 10-year period. The project would essentially be completed within the first five years at the level of the C Budget. Table 65 is a budget summary for Project B-15.

TABLE 65. Summary of Recommended Budgets for Power
Economic Analysis Project for Brine Resource
Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-15 Power Economics Analysis</u>	<u>0 (0.41)</u>	<u>0.2 (0.47)</u>	<u>0.4 (0.55)</u>
01 - Model of Fluid Handling System	0 (0.06)	0.06 (0.12)	0.15 (0.15)
03 - Model of Power Conversion System Elements	0 (0.1)	0.1 (0.1)	0.1 (0.1)
05 - Model for Tradeoff Analysis	0 (0.15)	0.04 (0.15)	0.15 (0.15)
07 - Final POCE Resource Analysis	0 (0.1)	0 (0.1)	0 (0.15)

B-16 Multiple Use of Resource

The brine resource offers reasonable possibility for uses of the resource other than power production. The area of chemical byproduct recovery appears to be the most promising and tasks have been recommended toward that end. The economic feasibility will undoubtedly be site-dependent. The tremendous amounts of chemicals existing in the hypersaline brines have attracted commercial interest for many years, but no commercial venture has been successful to date.

This project is not funded under the A Budget. The majority of the funds in the higher budgets are allocated in the first five years to provide a greater chance for successful demonstration within the 10-year resource development period. Table 66 is a budget summary for Project B-16.

TABLE 66. Summary of Recommended Budgets for Multiple Use of Resource Project in Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-16 Multiple Use of Resource</u>	-	2.0 (2.0)	2.0 (2.5)
01 - Byproduct Recovery Studies	-	0.3 (0.3)	0.3 (0.3)
03 - Land Use Studies	-	0.1 (0.1)	0.1 (0.1)
05 - Waste Product Utilization	-	0.1 (0.1)	0.1 (0.1)
07 - Byproduct Recovery Pilot Plant	-	1.5 (1.5)	1.5 (2.0)

B-17 Utilization Plan

The utilization plan is included as a separate project to assure that the means for dissemination of information will be included during the scoping and planning stages of resource development. Tasks are included to provide information to government, industry and the public in a timely fashion. Provisions have further been made to publish the information in a precise technical reference form such as handbooks as a background for future work. Funding is not recommended during the first five years under the A Budget due to lack of funds. However, all of the tasks are funded during the second five years. The B and C Budgets have most of the tasks spread evenly throughout the first 7 to 8 years of the program. Table 67 is a budget summary of Project B-17.

TABLE 67. Summary of Recommended Budgets for Utilization Plan Project for Brine Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-17 Utilization Plan</u>	0 (0.85)	0.5 (1.5)	1.1 (1.95)
01 - Seminars and Workshops	0 (0.1)	0.1 (0.15)	0.15 (0.25)
03 - Professional Papers	0 (0.15)	0.1 (0.15)	0.15 (0.25)
05 - Handbooks	0 (0.2)	0 (0.35)	0.35 (0.6)

07 - Textbooks	0 (0.15)	0.15 (0.3)	0.2 (0.3)
09 - Training Programs	0 (0.05)	0 (0.15)	0.07 (0.15)
11 - Educational Films	0 (0.1)	0.07 (0.2)	0.1 (0.2)
13 - Flyers and Brochures	0 (0.1)	0.08 (0.2)	0.08 (0.2)

Table 68 is a summary of the recommended funding for the entire brine resource program.

Scheduling and Milestones

The three pilot plants represent the major POCE's within the brine resource program. Other POCE's will also be performed in projects directed toward design and construction of successful pilot plants. The nature and scheduling of POCE's are influenced primarily by budget restrictions at the three levels of funding. The principal POCE's and milestones for successful execution are discussed below for each budget level.

The restrictive allocation for the A Budget precludes construction of a pilot plant or scheduling of other POCE's within the first five years. The development of critical equipment components can be transferred in part from development projects in other resource programs. The only pilot plant scheduled during the second five years in the A Budget is a "state-of-the-art" plant which requires primarily fluid chemistry, materials research and extended knowledge of reservoir characteristics rather than actual equipment development. Tasks relating to fluid chemistry, corrosion, scaling, reinjection technology and reservoir modeling are funded at an adequate level within the first five years of the A Budget. This will permit straightforward design, construction and operation of the "state-of-the-art" plant at the onset of the second five years of the resource development program.

The B and C Budgets include a "state-of-the-art" plant ready to operate at the end of the fifth year. The following milestones are required before the final plant design is completed: Phase 0 planning, location of a suitable reservoir, operation of successful production and reinjection wells, verification of the reservoir simulation model, proof that reinjection is

feasible over extended periods, and successful programs in materials research and fluid chemistry. Environmental surveys and impact statements and institutional problems would have to be completed or resolved before the plant became operational. All of the milestones for the "state-of-the-art" pilot plant are either scheduled for completion or well underway before final plant design begins in January of 1977. Perhaps the single most critical milestone is locating a suitable reservoir very early in the initial five years and establishing that adequate brine is available from self-pumping wells. The probability is high that such a reservoir could be found in the Imperial Valley of California.

Additional POCE's in the initial five years of the B Budget include the establishment of a fluid withdrawal/reinjection loop in a brine reservoir, completion of reservoir hydrothermal simulation model, development of critical equipment for an indirect power generation cycle, successful development of an underground cavity for steam flashing, and operation of a byproduct recovery pilot plant. The primary difference between the A and B Budget POCE's is scheduling, although the C Budget includes equipment development not funded in the B Budget.

The milestones for establishment of fluid withdrawal/reinjection loops are location of suitable reservoirs, characterization of the geothermal fluid and reservoir formation, development of a working reservoir hydrothermal simulation model and completion of reinjection technology tasks. These milestone projects and tasks are scheduled for completion within the first three years of the brine development program.

Principal milestones for the reservoir hydrothermal model POCE are characterization of the geothermal fluid properties and reservoir formation. Some information is available from past and ongoing projects which will provide enough background to start the model development and inputs can be added as new data become available from the brine reservoir assessment programs.

The POCE's for critical equipment development needed for an indirect power generation cycle include a deep-well pump, advances in conventional

heat exchanger technology and development of a satisfactory binary fluid cycle for the higher temperature brine reservoirs. An advanced nonconventional heat exchanger such as a down-hole system is included only in the C Budget and could possibly be completed within the first five years. The significant milestones for all critical equipment development are primarily materials research, characterization of the brines, and chemical treatment studies. All of the required milestone tasks are scheduled either for completion or are well underway before the equipment is fabricated and tested. One potentially problematic milestone not included within the brine resource development program is establishment of a test bed facility. It is assumed that the problem can be overcome by either using test facilities developed under other resource programs or locating existing geothermal "wells of opportunity".

The milestones for development of an underground cavity to serve as a steam flashing chamber are limited to location of a suitable site and the tasks within the Thermochemistry and Reservoir Assessment Projects; all are scheduled before commencement of the cavity task.

The significant milestones for the byproduct recovery pilot plant are location and assessment of a suitable reservoir site. Geothermal fluid characterization results will be available before the final plant design commences. Further decisions as to the economic viability of byproduct recovery operations will be based on preliminary results from several concurrent projects such as reinjection technology and establishment of fluid withdrawal/reinjection loops.

Figures 17-19 provide sequenced schedules for the major tasks for the five- and ten-year A, B, and C Budgets.

TABLE 68. Summary of Recommended Budgets for Brine
Resource Subprogram Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total Sub-Program Budget</u>	<u>5.30(24.73)</u>	<u>30.00(52.54)</u>	<u>36.60(78.62)</u>
<u>B-00 Scoping and Planning</u>	<u>0.10(0.10)</u>	<u>0.50(0.50)</u>	<u>0.60(0.60)</u>
01 - Exploration	0 (0)	0 (0)	0 (0)
02 - Assessment	0.02(0.02)	0.03(0.03)	0.03(0.03)
03 - Reservoir Develop- ment - Modeling	0.01(0.01)	0.02(0.02)	0.02(0.02)
04 - Reservoir Develop- ment - Production Wells	0 (0)	0.03(0.03)	0.03(0.03)
05 - Reservoir Develop- ment - Stimulation	0 (0)	0.01(0.01)	0.04(0.04)
06 - Reinjection Tech- nology	0.02(0.02)	0.03(0.03)	0.03(0.03)
07 - Power Generation Cycles	0 (0)	0.05(0.05)	0.06(0.06)
08 - Thermochemistry	0.04(0.04)	0.06(0.06)	0.07(0.07)
09 - Equipment Design, Development and Test	0 (0)	0.05(0.05)	0.06(0.06)
10 - Pilot Plant Selec- tion and Design	0 (0)	0.04(0.04)	0.05(0.05)
11 - Construction of Pilot Plants	0 (0)	0.02(0.02)	0.02(0.02)
12 - Pilot Plant Operation	0 (0)	0 (0)	0 (0)
13 - Supporting Research	0 (0)	0.05(0.05)	0.07(0.07)
14 - Environmental Studies	0.01(0.01)	0.02(0.02)	0.03(0.03)
15 - Power Economic Analysis	0 (0)	0.04(0.04)	0.04(0.04)
16 - Multiple Use of Resource	0 (0)	0.03(0.03)	0.03(0.03)
17 - Utilization Plan	0 (0)	0.02(0.02)	0.02(0.02)
<u>B-01 Exploration</u>	<u>0 (0)</u>	<u>0 (0)</u>	<u>0 (0)</u>

TABLE 68. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-02 Assessment</u>	<u>2.00(5.00)</u>	<u>3.00(7.40)</u>	<u>4.00(10.60)</u>
01 - Surface Mapping	0.15(0.45)	0.25(0.60)	0.45(0.90)
03 - Test Wells	1.00(3.00)	1.40(4.20)	1.80(6.00)
05 - Fluid Characterization	0.20(0.50)	0.30(0.90)	0.30(1.20)
07 - Characterization of Formations	0.15(0.30)	0.25(0.50)	0.25(0.70)
09 - Mass Transport Studies	0.50(0.75)	0.80(1.20)	1.20(1.80)
<u>B-03 Reservoir Development - Modeling</u>	<u>0.10(0.10)</u>	<u>0.40(0.40)</u>	<u>0.40(0.40)</u>
01 - Three-Dimensional Hydrothermal Model	0.10(0.10)	0.40(0.40)	0.40(0.40)
<u>B-04 Reservoir Development - Production Wells</u>	<u>0 (5.00)</u>	<u>3.00(7.50)</u>	<u>4.00(12.50)</u>
01 - Production and ReInjection Wells	0 (5.00)	3.00(7.50)	4.00(12.50)
<u>B-05 Reservoir Development - Stimulation</u>	<u>0 (0)</u>	<u>1.30(1.30)</u>	<u>1.30(1.30)</u>
01 - Stimulation Feasibility Study	0 (0)	0.05(0.05)	0.05(0.05)
02 - Tests of Stimulation Techniques	0 (0)	0.45(0.45)	0.45(0.45)
04 - Underground Cavity Experiments	0 (0)	0.80(0.80)	0.80(0.80)
<u>B-06 Reinjection Technology</u>	<u>0.60(0.60)</u>	<u>3.00(3.00)</u>	<u>4.20(4.20)</u>
01 - Chemical Treatment Methods	0.15(0.15)	0.45(0.45)	0.45(0.45)
02 - Verification of Reinjection Techniques	0.40(0.40)	1.10(1.10)	1.10(1.10)
04 - Alternative Reinjection Locations	0.05(0.05)	0.75(0.75)	1.20(1.20)
06 - Mechanical Stimulation of Formation	0 (0)	0.70(0.70)	1.00(1.00)
08 - Chemical Treatment of Formation	0 (0)	0 (0)	0.45(0.45)

TABLE 68. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-07 Power Generation Cycles</u>	<u>0 (0)</u>	<u>0.20(0.38)</u>	<u>0.50(0.50)</u>
01 - Evaluate Physical, Chemical and Thermodynamic Properties	0 (0)	0.04(0.04)	0.04(0.04)
03 - Evaluate Binary Fluid Systems	0 (0)	0.03(0.05)	0.05(0.05)
05 - Evaluate Systems Other Than Turbines	0 (0)	0.06(0.08)	0.11(0.11)
07 - Select Optimum Systems	0 (0)	0.02(0.02)	0.03(0.03)
09 - Develop New Binary Fluids	0 (0)	0 (0.06)	0.10(0.10)
11 - Evaluate Nonconventional Methods	0 (0)	0.05(0.07)	0.07(0.07)
13 - Design Advanced Expansion Machines	0 (0)	0 (0.06)	0.10(0.10)
<u>B-08 Thermochemistry</u>	<u>2.50(2.50)</u>	<u>2.50(2.50)</u>	<u>2.50(2.50)</u>
01 - Materials Research Tests	0.50(0.50)	0.50(0.50)	0.50(0.50)
03 - Corrosion, Erosion and Scaling Tests	0.40(0.40)	0.40(0.40)	0.40(0.40)
05 - Deposition Kinetics Studies	0.50(0.50)	0.50(0.50)	0.50(0.50)
07 - Fluid Chemical Treatment Studies	0.30(0.30)	0.30(0.30)	0.30(0.30)
09 - Cathodic Protection Systems	0.60(0.60)	0.60(0.60)	0.60(0.60)
11 - Chemical Methods for Scale Removal	0.20(0.20)	0.20(0.20)	0.20(0.20)
<u>B-09 Equipment Design, Development and Test</u>	<u>0 (1.30)</u>	<u>3.10(3.60)</u>	<u>4.70(5.00)</u>
01 - Design and Construct Test Bed Facility	0 (0)	0 (0)	0 (0)
02 - Operate Test Bed Facility	0 (0)	0 (0)	0 (0)

TABLE 68. (continued)

	<u>A Budget</u>		<u>B Budget</u>		<u>C Budget</u>	
04 - Design and Test Heat Exchanger (Conventional)	0	(0.40)	0.60	(0.60)	0.60	(0.60)
06 - Design and Test Reinjection Pumps	0	(0.20)	0.30	(0.30)	0.30	(0.30)
08 - Design and Test Binary Fluid Cycle Components	0	(0)	0.30	(0.60)	0.70	(0.70)
10 - Design & Test Equip- ment for the Removal of Noncondensable Gases	0	(0)	0.40	(0.40)	0.40	(0.40)
12 - Design and Test Deep Well Pump	0	(0.60)	1.00	(1.00)	2.00	(2.00)
14 - Design and Test Mechanical Scale Removal Devices	0	(0.10)	0.20	(0.20)	0.20	(0.20)
16 - Advanced Heat Exchanger Design and Test	0	(0)	0.30	(0.50)	0.50	(0.80)
<u>B-10 Pilot Plant Design</u>	<u>0</u>	<u>(0.80)</u>	<u>0.80</u>	<u>(1.70)</u>	<u>0.80</u>	<u>(2.90)</u>
01 - "State-of-the-Art" Plant for Low Salinity Reservoir	0	(0.80)	0.80	(0.80)	0.80	(0.80)
03 - Plant for Hyper- saline Reservoir	0	(0)	0	(0.90)	0	(0.90)
05 - Special Purpose Plant	0	(0)	0	(0)	0	(1.20)
<u>B-11 Construction of Pilot Plants</u>	<u>0</u>	<u>(6.00)</u>	<u>6.00</u>	<u>(14.00)</u>	<u>6.00</u>	<u>(24.00)</u>
01 - "State-of-the-Art" Plant for Low Salinity Reservoir	0	(6.00)	6.00	(6.00)	6.00	(6.00)
03 - Plant for Hyper- saline Reservoir	0	(0)	0	(8.00)	0	(8.00)
05 - Special Purpose Plant	0	(0)	0	(0)	0	(10.00)

TABLE 68. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>B-12 Pilot Plant Operation</u>	<u>0 (1.70)</u>	<u>0 (2.40)</u>	<u>0 (3.60)</u>
01 - "State-of-the-Art" Plant for Low Salinity Reservoir	0 (1.70)	0 (2.00)	0 (2.00)
03 - Plant for Hyper- saline Reservoir	0 (0)	0 (0.40)	0 (0.40)
05 - Special Purpose Plant	0 (0)	0 (0)	0 (1.20)
<u>B-13 Supporting Research</u>	<u>0 (0)</u>	<u>3.00(3.00)</u>	<u>3.00(4.00)</u>
01 - Improved Techniques for Drilling Wells	0 (0)	0.90(0.90)	0.90(0.90)
03 - Design and Test of Fluid Handling Components	0 (0)	0.50(0.50)	0.50(0.50)
05 - Design and Test of Steam Flashing Units	0 (0)	0.30(0.30)	0.30(0.30)
07 - Design and Test of Steam Condensers	0 (0)	0.50(0.50)	0.50(0.50)
09 - Design and Test of Borehole Screens	0 (0)	0.20(0.20)	0.20(0.20)
11 - Develop High Tempera- ture Monitoring Instruments	0 (0)	0.60(0.60)	0.60(1.60)
<u>B-14 Environmental Studies</u>	<u>0 (0.37)</u>	<u>0.50(0.89)</u>	<u>1.10(1.52)</u>
01 - Assess Potential Seismic Effects	0 (0.12)	0.05(0.15)	0.15(0.15)
03 - Develop Contaminant Removal Systems	0 (0)	0.14(0.15)	0.50(0.50)
05 - Environmental Surveys of Sites	0 (0.12)	0.06(0.18)	0.11(0.24)
07 - Environmental Moni- toring	0 (0.03)	0 (0.06)	0 (0.09)
09 - Environmental Impact Statements	0 (0.10)	0.10(0.20)	0.10(0.30)
11 - Develop Noise Abatement Devices	0 (0)	0.15(0.15)	0.24(0.24)

TABLE 68. (continued)

	<u>A Budget</u>		<u>B Budget</u>	<u>C Budget</u>
<u>B-15 Power Economics Analysis</u>	0	(0.41)	0.20(0.47)	0.40(0.55)
01 - Model of Fluid Handling System	0	(0.06)	0.06(0.12)	0.15(0.15)
03 - Model of Power Conversion System Elements	0	(0.10)	0.10(0.10)	0.10(0.10)
05 - Model for Trade-off Analysis	0	(0.15)	0.04(0.15)	0.15(0.15)
07 - Final POCE Resource Analysis	0	(0.10)	0 (0.10)	0 (0.15)
<u>B-16 Multiple Use of Resource</u>	0	(0)	2.00(2.00)	2.00(2.50)
01 - By-Product Recovery Studies	0	(0)	0.30(0.30)	0.30(0.30)
03 - Land Use Studies	0	(0)	0.10(0.10)	0.10(0.10)
05 - Waste Product Utilization	0	(0)	0.10(0.10)	0.10(0.10)
07 - By-Product Pilot Plant Recovery	0	(0)	1.50(1.50)	1.50(2.00)
<u>B-17 Utilization Plan</u>	0	(0.85)	0.50(1.50)	1.10(1.95)
01 - Seminars & Workshops	0	(0.10)	0.10(0.15)	0.15(0.25)
03 - Professional Papers	0	(0.15)	0.10(0.15)	0.15(0.25)
05 - Handbooks	0	(0.20)	0 (0.35)	0.35(0.60)
07 - Textbooks	0	(0.15)	0.15(0.30)	0.20(0.30)
09 - Training Programs	0	(0.05)	0 (0.15)	0.07(0.15)
11 - Educational Films	0	(0.10)	0.07(0.20)	0.10(0.20)
13 - Fliers and Brochures	0	(0.10)	0.08(0.20)	0.08(0.20)

FIGURE 17. Hot Brine Geothermal Power - A Budget (Fiscal Year)

FIGURE 18. Hot Brine Geothermal Power - B Budget (Fiscal Year)

FIGURE 18. (Continued)

FIGURE 19. Hot Brine Geothermal Power - C Budget (Fiscal Year)

FIGURE 19. (continued)

E. GEOPRESSURED RESOURCES

Geopressured resources contain potential energy in the form of hot, high pressure water and methane. The water was trapped during the original deposition of the sediments. The sediments are under near lithostatic pressure, up to 15,000 psi, from overlying sediments. Since temperatures and pressures, in general, increase with depth, deeper reservoirs would tend to have a greater recoverable energy potential than shallow reservoirs. In more shallow geopressure zones, the water is typically more saline than sea water; in deeper zones the water freshens and may be almost potable.

Location

Geopressured resources are widely distributed in sedimentary basins. Extensive geopressured zones exist along the Gulf coast. Jones,⁽¹⁾ for instance, reported data on many geopressured aquifers between depths of 1,300 and 17,000 feet, and analyzed 175 South Louisiana geopressured reservoirs above a depth of 11,000 feet. Other known occurrences are in Wyoming and California. Geopressured zones occur throughout the world. In Hungary, lower temperature and pressure water from a sedimentary basin is used for home heating.

Value of Resource

"Geopressured deposits occur in continuous belts, are commonly bounded by regional faults, and extend for hundreds of miles. The belt in the northern Gulf of Mexico basin is about 750 miles long, from the Rio Grande of Texas to the Mississippi Sound. It underlies the Coastal Plain inland for a distance of 60 to 100 miles and underlies the Continental Shelf wherever drilled up to 150 miles offshore. The geopressured zones are not continuous over the entire region but are thought to exist in lenses, blocks, and partitioned volumes as a result of the complex geological processes accompanying the rapid (geologically) subsidence of the geosyncline."⁽²⁾

(1) Paul H. Jones. "Hydrodynamics of Geopressure in the Northern Gulf of Mexico Basin", Journal of Petroleum Technology, pp. 803-810, July 1969.

(2) Walter J. Hickel. Geothermal Energy, University of Alaska, p. 16, 1972.

Bechtel estimates of the energy potential from geopressed zones, under "crash" conditions, range up to 500,000 MWe by the year 2000.⁽¹⁾ Despite this large value, geopressed energy, in comparison with other forms of geothermal energy, is projected to contribute only a fraction (5-10%) of the total geothermal energy supply.⁽²⁾ Nonetheless, the potential energy in geopressed zones is enormous.

State-of-the-Art

There is no existing production of energy from geopressed zones in this country. Information on sustained flow tests from geopressed zones is scarce. However, one reservoir produced 6 billion cubic feet of gas, 1 million barrels of salt water, and 170,000 barrels of condensate over a 6.5-year period.⁽³⁾ During this period the bottom hole pressure dropped only 1,100 psi from the initial 10,000 psi. Many geopressed wells, however, are reported to produce for only brief periods.⁽⁴⁾ Geopressed resources are depletable since there is no continuing supply of water. Much uncertainty exists on the sustainable rate of production and ultimate energy obtainable from geopressed zones. For these reasons there is some doubt that geopressed zones will ever become a viable energy resource.

Problems

With geopressed resources, the main question to be resolved is whether flow rates high enough for efficient energy production can be sustained from a reservoir. The research program outlined below is directed toward this end. Assuming a viable flow rate can be demonstrated, several other problems emerge. Large quantities of water must be disposed of safely and economically. Equipment for controlling the high pressure water

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- (1) M. Carasso, A Technological Assessment of Geothermal Energy Resource Development, Bechtel Corp., August 1975.
 - (2) Ibid.
 - (3) Jones, op. cit., p. 808.
 - (4) R. Greider, Standard Oil of California, personal communication, December 21, 1973.

must be developed. Any potential subsidence effects must be understood and guarded against. Effective methods to extract and use the contained methane are required. The conversion of thermal energy to electricity, once the pressure is reduced, is not expected to create any new problems since other geothermal hot and warm water systems will operate in the same temperature range. Thermal conversion technology developed under these resource subprograms should apply directly to geopressured systems. The extraction of kinetic energy is probably not critical to the viability, but efficient means of recovery of kinetic energy would greatly increase the attractiveness of geopressured resources. Some geopressured zones produce nearly potable water; productive uses for this water would also enhance the economic potential from geopressured zones.

Development Strategy

A program to demonstrate the recoverable energy potential of geopressured energy resources is recommended. Under the A Budget the principal objective is to achieve a sustained flow rate from a geopressured well over a three-year period. The flow rate should be high enough to demonstrate a potential for economic energy recovery. The well would be carefully selected to be representative of a substantial energy resource. Under the B and C Budgets, the principal objective will also be to achieve sustained flow rates; but three wells at different locations, each representative of a substantial resource, will be flow tested. Two additional supporting wells will be sunk near the best well to determine the uniformity and areal extent of the reservoir. These three wells are expected to provide the flow for a pilot plant to be constructed and operated in the second 5-year period. Also, under the B and C Budgets an experiment is planned to stimulate the flow from a low permeability geopressured zone if feasibility studies indicate probable success. Also, under the B and C Budgets, experiments on the reinjection of waste water are planned. In most geopressured areas, safe disposal of the water at sea will be possible. However, in some areas reinjection into overlying formations or nearby abandoned wells may be required. Reinjection might also be effective in reducing risk of subsidence.

Because doubts persist about the capability of geopressured zones to maintain a sufficient flow for efficient energy production, demonstration of this capability over a period of several years should be required prior to construction of a pilot plant. If this flow is successfully demonstrated the pilot plant will be built and operated during the second 5-year period. The pilot plant design will be based on demonstrated technology developed under the hot and warm water subprograms.

The projects and their recommended funding are shown in Table 69. These projects are discussed in detail below and in the task sheets in Appendix B.

TABLE 69. Summary of Recommended Project Budgets for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>4.0 (37.61)</u>	<u>15.0 (37.52)</u>	<u>18.1 (38.71)</u>
G-00 - Planning Studies	0.05 (0.3)	0.3 (0.3)	0.4 (0.4)
G-02 - Assessment	0.75 (2.75)	2.75 (2.75)	3.75 (3.75)
G-03 - Reservoir Modeling	0 (0.5)	0.2 (0.5)	0.2 (0.5)
G-04 - Reservoir Development	1.0 (4.5)	4.0 (4.5)	4.5 (4.5)
G-05 - Stimulation	0.05 (1.0)	1.0 (1.0)	1.0 (1.0)
G-06 - Reinjection Technology	0.1 (1.1)	1.1 (1.1)	1.1 (1.1)
G-07 - Power Generation Cycles	0.1 (0.36)	0.27 (0.27)	0.36 (0.36)
G-08 - Thermochemistry	0.15 (2.5)	0.9 (2.5)	1.14 (2.5)
G-09 - Equipment Design and Testing	0.95 (6.5)	1.45 (6.5)	1.9 (6.5)
G-10 - Pilot Plant Design	0 (1.0)	0.73 (1.0)	1.0 (1.0)
G-11 - Pilot Plant Construction	0 (7.0)	0 (7.0)	0 (7.0)
G-12 - Pilot Plant Operation	- (3.0)	0 (3.0)	0 (3.0)
G-13 - Supporting Research	0.2 (2.8)	0.4 (2.8)	0.5 (2.8)
G-14 - Environmental Studies	0.4 (1.7)	1.1 (1.7)	1.3 (1.7)
G-15 - Power Economics Analysis	0.05 (0.7)	0.3 (0.7)	0.35 (0.7)
G-16 - Multiple Use of Resource	0 (0.4)	0.1 (0.4)	0.1 (0.4)
G-17 - Utilization	0.2 (1.5)	0.4 (1.5)	0.5 (1.5)

Projects

G-00 Planning Studies

These are Phase 0 planning and scoping studies. The scope and funding increases with the size of the budget.

TABLE 70. Summary of Recommended Budgets for Planning Studies
Project for Geopressured Resource Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
G-00 Planning Studies	0.05 (0.3)	0.3 (0.3)	0.4 (0.4)

G-02 Resource Assessment

A comprehensive analysis of existing data (Task 01) would be performed for the Gulf Coast region (A Budget) and for the entire country (B and C Budgets). Based on this analysis, potential sites for geopressure demonstration would be selected (Task 02). An exploratory well would be developed (Task 03) at one site under Budget A and at three sites under Budgets B and C. The increased number of sites will speed the rate at which data on the usefulness of this resource can be gathered. In addition, more sites will increase the reliability of resource assessment predictions.

TABLE 71. Summary of Recommended Budgets for Resource
Assessment Project for Geopressured Resource
Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-02 Assessment</u>	<u>0.75 (2.75)</u>	<u>2.75 (2.75)</u>	<u>3.75 (3.75)</u>
01 - Analyze Existing Data	0.35 (0.65)	0.65 (0.65)	0.65 (0.65)
02 - Site Selection	0.05 (0.15)	0.1 (0.1)	0.1 (0.1)
03 - Exploratory Wells	0.35 (2.0)	2.0 (2.0)	3.0 (3.0)

G-03 Reservoir Modeling

The general model of geothermal resources would be adapted and applied to geopressed resources under Budgets B and C. No work is planned under Budget A until the second 5-year period.

TABLE 72. Summary of Recommended Budgets for Reservoir Modeling Project for Geopressed Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-03 Reservoir Modeling</u>	<u>0 (0.5)</u>	<u>0.2 (0.5)</u>	<u>0.2 (0.5)</u>
01 - Simulation Models	- (0.5)	0.2 (0.5)	0.2 (0.5)

G-04 Reservoir Development

Flow tests (Task 01) would be conducted over a three-year period on each of the exploratory wells. The best site would be developed in more detail with two additional supporting wells (Task 02) under B and C Budgets.

TABLE 73. Summary of Recommended Budgets for Reservoir Development Project for Geopressed Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-04 Reservoir Development -</u> <u>Test Wells</u>	<u>1.0 (4.5)</u>	<u>4.0 (4.5)</u>	<u>4.5 (4.5)</u>
01 - Flow Tests	1.0 (2.5)	2.0 (2.5)	2.5 (2.5)
02 - Supporting Wells	0 (2.0)	2.0 (2.0)	2.0 (2.0)

G-05 Stimulation

A feasibility study (Task 01) would be conducted to determine the potential for increased energy recovery from geopressed formations using stimulation techniques. This study would also develop plans for further experiments and tests of stimulation methods. Stimulation tests (Task 02) would be conducted in the initial 5-year period under B and C Budgets and

later under Budget A. If the exploratory wells do not achieve sufficient flow rates, the viability of geopressured resources will depend on the development of effective stimulation techniques.

TABLE 74. Summary of Recommended Budgets for Stimulation Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-05 Stimulation</u>	<u>0.05 (1.0)</u>	<u>1.0 (0)</u>	<u>1.0 (1.0)</u>
01 - Scoping Study	0.05 (0.1)	0.1 (0.1)	0.1 (0.1)
02 - Stimulation Tests	0 (0.9)	0.9 (0.9)	0.9 (0.9)

G-06 Reinjection Technology

A scoping study (Task 01) of the potential for reinjection of geopressured waste water would be conducted. Possible sites include overlying formations and nearby abandoned wells. The potential effect of reinjection on seismic and subsidence activity would be analyzed. The study would develop recommendations and a plan for further reinjection experiments and field tests (Task 02).

TABLE 75. Summary of Recommended Budgets for Reinjection Technology for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-06 Reinjection Technology</u>	<u>0.1 (0.1)</u>	<u>1.1 (1.1)</u>	<u>1.1 (1.1)</u>
01 - Scoping Study	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
02 - Reinjection Tests	0 (1.0)	1.0 (1.0)	1.0 (1.0)

G-07 Power Generation Cycles

Conceptual design studies (Task 01) of potential power generation cycles for geopressured resources using all three forms of energy - thermal, kinetic and methane - would be undertaken. This study would cover the entire range

of conditions expected in geopressured resources. The purpose of this study is to identify limitations in existing technology and the need for further research and development. Under B and C Budgets further detailed analyses, if needed, of methane utilization (Task 03), kinetic energy recovery (Task 05), and thermal energy utilization (Task 07) would be undertaken during the initial 5-year period. Task 07 will be conducted later; its purpose will be to apply the results from power cycle research programs performed under the geothermal hot and warm water subprograms to the geopressured resources.

TABLE 76. Summary of Recommended Budgets for Power Generation Cycles Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-07 Power Generating Cycles</u>	<u>0.1 (0.36)</u>	<u>0.27 (0.27)</u>	<u>0.36 (0.36)</u>
01 - Design Studies	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
03 - Methane Utilization Studies	0 (0.1)	0.08 (0.08)	0.1 (0.1)
05 - Kinetic Energy Utilization	0 (0.1)	0.05 (0.05)	0.1 (0.1)
07 - Thermal Energy Utilization	0 (0.06)	0.04 (0.04)	0.06 (0.06)

G-08 Thermochemistry

Applied research in thermochemistry would be directed toward providing sound bases for materials selection and pilot plant equipment design. High pressures, the coastal salt water environment, applications of the water impulse turbine, and the composition of geopressured fluids will probably create materials and equipment problems far different (e.g., corrosion, scaling, maintenance, design, material selecting and instrumentation) from those encountered with other geothermal resources. Applied research would be conducted on silica and salt deposition (Task 01), corrosion and erosion (Task 03), fluid flow (Task 05), and characterization analyses of geopressured fluids (Task 07). Corrosion and erosion are expected to be severe problems. The resolution of the problems could require large-scale laboratory and field tests and even greater funding.

TABLE 77. Summary of Recommended Budgets for Thermochemistry Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-08 Thermochemistry</u>	<u>0.15 (2.5)</u>	<u>0.9 (2.5)</u>	<u>1.14 (2.5)</u>
01 - Deposition Research	0 (0.4)	0 (0.4)	0.1 (0.4)
03 - Corrosion Research	- (1.1)	0.5 (0.4)	0.64 (1.1)
05 - Fluid Flow Research	0 (0.5)	0.1 (0.5)	0.1 (0.5)
07 - Characterization Analysis	0.15 (0.5)	0.3 (0.5)	0.3 (0.5)

G-09 Equipment Design, Fabrication and Testing

To meet applications beyond the state-of-the-art, prototype equipment for a pilot plant will be designed, built and tested. Special valves and piping (Task 01) will be required for both the flow tests and the pilot plant. A safe reliable system to control and reduce the high pressure (Task 03) will also be required for both the flow tests and the pilot plant. If design studies demonstrate technical and economic feasibility, a high pressure water impulse turbine (Task 05) to recover the kinetic energy would be developed. Efficient methane recovery equipment (Task 07) is critical to the viability of geopressured systems. Special particulate removal equipment (Task 09) capable of operating under high pressures and flow rates will be required for the pilot plant. A fluid pretreatment (ahead of the heat exchangers) system (Task 11) might be required to reduce corrosion and scaling. Depending on the fluid, temperature and composition, and the thermodynamic cycle selected, a specially designed steam heat exchanger (Task 13) or a binary fluid heat exchanger (Task 15), or both, might be required. Tasks 01, 03 and 07 would be undertaken first since these data are required to establish design criteria for the pilot plant. The other tasks would be undertaken if information developed under Tasks G-07 and G-08 determined that reliable equipment design criteria did not exist in these areas.

TABLE 78. Summary of Recommended Budgets for Equipment Design, Fabrication and Testing Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-09 Equipment Design, Fabrication and Testing</u>	0.95 (6.5)	1.45 (6.5)	1.9 (6.5)
01 - Valves and Piping	0.35 (0.8)	0.5 (0.8)	0.5 (0.8)
03 - Pressure Reduction	0.3 (0.4)	0.35 (0.4)	0.4 (0.4)
05 - Water Impulse Turbine	0 (3.5)	0 (3.5)	0.3 (3.5)
07 - Methane Extract	0.3 (0.5)	0.5 (0.5)	0.5 (0.5)
09 - Particulate Removal	0 (0.4)	0.1 (0.4)	0.2 (0.4)
11 - Fluid Pretreatment	0 (0.2)	0 (0.2)	0 (0.2)
13 - Steam HX	0 (0.3)	0 (0.3)	0 (0.3)
15 - Binary HX	0 (0.4)	0 (0.4)	0 (0.4)

G-10 Pilot Plant Design

Under B and C Budgets, a conceptual design (Task 01) for the pilot plant would be completed. The detailed pilot plant design (Task 02) would be completed under C Budget and nearly completed under B Budget. The site for the supporting wells and the pilot plant would be selected under B and C Budgets (Task 03).

TABLE 79. Summary of Recommended Budgets for Pilot Plant Design Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-10 Pilot Plant Design</u>	0 (1.0)	0.73 (1.0)	1.0 (1.0)
01 - Conceptual Design	0 (0.1)	0.1 (0.1)	0.1 (0.1)
02 - Detailed Design	0 (0.8)	0.53 (0.8)	0.8 (0.8)
03 - Site Selection	0 (0.1)	0.1 (0.1)	0.1 (0.1)

G-11 Pilot Plant Construction

No construction funds are provided for the pilot plant in the initial 5-year period.

TABLE 80. Summary of Recommended Budgets for Pilot Plant Construction Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
G-11 Pilot Plant Construction	0 (7.0)	0 (7.0)	0 (7.0)

G-12 Pilot Plant Operation

No funds are provided for pilot plant operation in the first 5-year period. (See Development Strategy, p. 156.)

TABLE 81. Summary of Recommended Budgets for Pilot Plant Operation Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
G-12 Pilot Plant Operation	0 (3.0)	0 (3.0)	0 (3.0)

G-13 Supporting Research

Since the high pressure water partially supports the overlying sediments, a detailed evaluation of potential subsidence and seismic problems (Task 05) will be undertaken. Special instrumentation (Task 07) will be required to monitor the flow, temperature and other characteristics of the geopressured fluids. Other supporting research on the development of high temperature and pressure packing materials (Task 01), production drilling improvements (Task 03), and the need for a high pressure test loop (Task 09) will be determined by program developments such as the need for high pressure tests on valves, special materials, or new component designs, during the initial 5-year period.

TABLE 82. Summary of Recommended Budgets for Supporting Research Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-13 Supporting Research</u>	<u>0.2 (2.8)</u>	<u>0.4 (2.8)</u>	<u>0.5 (2.8)</u>
01 - High Temperature/Pressure Packing Materials	0 (0.2)	0 (0.2)	0 (0.2)
03 - Production Drilling Improvements	0 (0.4)	0 (0.4)	0 (0.4)
05 - Subsidence-Seismic Research	0.2 (0.6)	0.4 (0.6)	0.4 (0.6)
07 - Instrumentation	0 (0.4)	0 (0.4)	0.1 (0.4)
09 - High Pressure Loop	- (0.2)	0 (0.2)	0 (1.2)

G-14 Environmental Studies

The general seismic-subsidence model developed in the E-14 subprogram will be adapted to geopressured resources (Task 01). This model will be adapted for geopressured resources using data obtained in the preceding project. Site surveys (Task 03) will be conducted and impact statements Task (04) will be prepared for each of the exploratory well locations. Methods and equipment for safe and effective disposal of the waste water (Task 06) will be developed. Environmental Monitoring (Task 08) will be conducted, as required, at each test site.

TABLE 83. Summary of Recommended Budgets for Environmental Studies Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-14 Environmental Studies</u>	<u>0.4 (1.7)</u>	<u>1.1 (1.7)</u>	<u>1.3 (1.7)</u>
01 - Subsidence-Seismic Model	0.05 (0.2)	0.1 (0.2)	0.1 (0.2)
02 - Site Survey	0.1 (0.3)	0.3 (0.3)	0.3 (0.3)
04 - Impact Statement	0.1 (0.3)	0.3 (0.3)	0.3 (0.3)
06 - Waste Treatment Equipment	0.1 (0.6)	0.3 (0.6)	0.5 (0.5)
08 - Monitoring Studies	0.05 (0.3)	0.1 (0.3)	0.1 (0.3)

G-15 Power Economic Analyses

Several economic analyses would be conducted throughout the research program to determine the economic incentives for further research and to provide information for design optimization and tradeoff analyses. These periodic analyses, covering all aspects of geopressure power generation, provide information to the program management which can be used to direct the program toward achieving economic goals. An initial analysis (Task 01) would be conducted at the completion of the resource assessment task (G-02-01). Another analysis (Task 03) would be conducted in conjunction with the power generation cycle design studies (G-07-01). Another analysis (Task 05) would be conducted based on the conceptual design of the pilot plant. Design optimization and tradeoff analyses (Task 07) would be conducted in conjunction with the detailed plant design. Reservoir optimization (Task 09) and other final resource economic analyses (Task 11) would be based on data developed in the research program and would be completed after the pilot plant operating period.

TABLE 84. Summary of Recommended Budgets for Power Economic Analyses Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-15 Power Economic Analysis</u>	<u>0.05 (0.7)</u>	<u>0.3 (0.7)</u>	<u>0.35 (0.7)</u>
01 - Initial Resource Development Analysis	0.02 (0.06)	0.06 (0.06)	0.06 (0.06)
03 - Power Generation Cycle Analysis	0.03 (0.06)	0.06 (0.06)	0.06 (0.06)
05 - Conceptual Design Analysis	0 (0.06)	0.06 (0.06)	0.06 (0.06)
07 - Design Optimization and Tradeoff	0 (0.17)	0.12 (0.17)	0.17 (0.17)
09 - Reservoir Optimization	0 (0.15)	0 (0.15)	0 (0.15)
11 - Field Resource Economic Analysis	0 (0.2)	0 (0.2)	0 (0.2)

G-16 Multiple Use of Resource

Economic utilization of some geopressed resources may depend on the development of multiple uses. Some of the geopressed zones contain low grade heat; some contain nearly potable water. An analysis of multiple use applications (Task 01) will be conducted under the B and C Budgets. This analysis would identify and recommend a development plan for those multiple use applications which extend the economic viability of certain geopressed reservoirs.

TABLE 85. Summary of Recommended Budgets for Multiple Use of Resource Project for Geopressed Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-16 Multiple Use of Resource</u>	<u>0 (0.4)</u>	<u>0.1 (0.4)</u>	<u>0.1 (0.4)</u>
01 - Alternative Applications	0 (0.4)	0.1 (0.4)	0.1 (0.4)

G-17 Utilization Project

In order to promote widespread dissemination and utilization of research results, a special budget for this purpose is provided. Since the output from most of the projects will be research reports, the utilization project will use other channels to review, evaluate, summarize, apply, and distribute this information. These channels include sponsorship of seminars and other meetings (Task 01), professional papers and review articles (Task 03), handbooks and textbooks (Task 05), training programs (Task 07), public information films, pamphlets and brochures (Task 09), and support for professional and standards society activities (Task 11).

TABLE 86. Summary of Recommended Budgets for Utilization Project for Geopressured Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-17 Utilization Project</u>	<u>0.2 (1.5)</u>	<u>0.4 (1.5)</u>	<u>0.5 (1.5)</u>
01 - Seminars, etc.	0.1 (0.2)	0.1 (0.2)	0.1 (0.2)
03 - Professional Papers	0.05 (0.15)	0.1 (0.15)	0.1 (0.15)
05 - Handbooks, etc.	0 (0.5)	0 (0.5)	0.1 (0.5)
07 - Training Programs	0 (0.3)	0 (0.3)	0 (0.3)
09 - Film	0 (0.1)	0.05 (0.1)	0.05 (0.1)
11 - Public Information	0.05 (0.15)	0.1 (0.15)	0.1 (0.15)
13 - Professional Societies	0 (0.1)	0.05 (0.1)	0.05 (0.1)

Proof-of-Concept Experiments and Significant Milestones

Several "proof-of-concept experiments" and significant milestones critical to demonstrating the viability of geopressured resources will be completed in the first 5-year period under the C Budgets.

1. A complete resource assessment of existing geopressured occurrences. (G02-01)
2. Prolonged full-scale flow tests on up to three wells (POCE). (G04-01)
3. Development of a computer model simulation of geopressured resources. (G03-01)
4. The demonstration of economically significant recoverable energy in a selected reservoir (POCE). (G04-02)
5. A demonstration of the capability to stimulate increased flow in a geopressured reservoir (POCE). (G05-02)
6. A demonstration of the safe disposal or reinjection of waste water from geopressured reservoirs (POCE). (G06-02)
7. A pilot plant design. (G10-02)

8. The design, fabrication, and successful testing of prototype equipment critical to the demonstration of geopressured resource viability:
 - a. Prototype valves and piping (POCE). (G09-01)
 - b. Prototype pressure control and reduction (POCE). (G09-03)
 - c. Efficient methane recovery (POCE). (G09-07)
9. A detailed characterization of geopressured fluids. (G08-07)
10. Determination of corrosion and erosion environments sufficient to specify material and equipment design requirements to meet the probable operating conditions. (G08)
11. A detailed evaluation of potential subsidence and seismic problems. (G13-05, G14-01)
12. Site surveys and the preparation of environmental impact statements. (G14-02, 04)
13. The evaluation of the economic potential for geopressured resources. (G16)
14. An evaluation of alternative applications for geopressured resources. (G16)

All of the above items would also be completed, but some to a more limited extent, under the B Budget. Under the A Budget, item 1 would be completed for the Gulf Coast only. Item 2 would be completed for one well only, and items 8, 9, 11, 12 and 13 would be completed to a limited extent only. Successful completion of each of the above items, with the exception of 3, is necessary to demonstrate the economic viability of geopressured resources. Decisions on continued funding for geopressure resource development and the level of funding for each project and task will depend on the timing and degree of success achieved in preceding tasks. Project and task schedules are shown in Figures 20, 21 and 22. The research tasks required to complete these proof-of-concept experiments and significant milestones are described in Appendix B. Complete budgets for geopressured resources are shown in Table 87. This table is a composite of the project budgets previously shown.

The prime objective in the first five years is to demonstrate that geopressure is (or is not) a viable energy resource (see Development Strategy, p. 156). If viability is demonstrated, a pilot plant generating electricity is planned for operation in the seventh year under the C Budget and in the eighth year under the B Budget. Under the A Budget, resource viability would not be demonstrated until the seventh year, and pilot plant operation would begin in the tenth year.

TABLE 87. Summary of Recommended Budgets for Geopressed Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>TOTAL</u>	<u>4.0(37.61)</u>	<u>15.0(37.52)</u>	<u>18.1(38.71)</u>
<u>G-00 - Planning Studies</u>	<u>0.50(0.30)</u>	<u>0.30(0.30)</u>	<u>0.40(0.40)</u>
<u>G-02 - Assessment</u>	<u>0.75(2.75)</u>	<u>2.75(2.75)</u>	<u>3.75(3.75)</u>
01 - Analyze Existing Data	0.35(0.65)	0.65(0.65)	0.65(0.65)
02 - Site Selection	0.05(0.15)	0.10(0.10)	0.10(0.10)
03 - Exploratory Wells	0.35(2.00)	2.00(2.00)	3.00(3.00)
<u>G-03 - Reservoir Development</u>	<u>- (0.50)</u>	<u>0.20(0.50)</u>	<u>0.20(0.50)</u>
01 - Develop Model	- (0.50)	0.20(0.50)	0.20(0.50)
<u>G-04 - Reservoir Development - Test Wells</u>	<u>1.00(4.50)</u>	<u>4.00(4.50)</u>	<u>4.50(4.50)</u>
01 - Flow Tests	1.00(2.50)	2.00(2.50)	2.50(2.50)
02 - Supporting Wells	- (2.00)	2.00(2.00)	2.00(2.00)
<u>G-05 - Stimulation</u>	<u>0.05(1.00)</u>	<u>1.00(1.00)</u>	<u>1.00(1.00)</u>
01 - Scoping Study	0.05(0.10)	0.10(0.10)	0.10(0.10)
02 - Stimulation Tests	- (0.90)	0.90(0.90)	0.90(0.90)
<u>G-06 - Reinjection Tech.</u>	<u>0.10(1.10)</u>	<u>1.10(1.10)</u>	<u>1.10(1.10)</u>
01 - Scoping Study	0.10(0.10)	0.10(0.10)	0.10(0.10)
02 - Reinjection Tests	- (1.00)	1.00(1.00)	1.00(1.00)
<u>G-07 - Power Generation Cycles</u>	<u>0.10(0.36)</u>	<u>0.27(0.27)</u>	<u>0.36(0.36)</u>
01 - Design Studies	0.10(0.10)	0.10(0.10)	0.10(0.10)
03 - Methane Utilization Studies	- (0.10)	0.08(0.08)	0.10(0.10)
05 - Kinetic Energy Utilization	- (0.10)	0.05(0.05)	0.10(0.10)
07 - Thermal Energy Utilization	- (0.06)	0.04(0.04)	0.06(0.06)

TABLE 87. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-08 - Thermochemistry</u>	<u>0.15(2.50)</u>	<u>0.9(2.50)</u>	<u>1.14(2.50)</u>
01 Deposition Research	- (0.40)	- (0.40)	0.10(0.40)
03 Corrosion Research	- (1.10)	0.5(1.10)	0.64(1.10)
05 Fluid Flow Research	- (0.50)	0.1(0.50)	0.10(0.50)
07 Characterization Analysis	0.15(0.50)	0.3(0.50)	0.30(0.50)
<u>G-09 - Equipment Design, Fabrication, Test.</u>	<u>0.95(6.50)</u>	<u>1.45(6.50)</u>	<u>1.9(6.50)</u>
01 Valves & Piping	0.35(0.80)	0.50(0.80)	0.5(0.8)
03 Pressure Reduction	0.30(0.40)	0.35(0.40)	0.4(0.4)
05 Water Impulse Turbine	- (3.50)	- (3.50)	0.3(3.5)
07 Methane Extract	0.30(0.50)	0.50(0.50)	0.5(0.5)
09 Particulate Removal	- (0.40)	0.10(0.40)	0.2(0.4)
11 Fluid Pre-Treatment	- (0.20)	- (0.20)	- (0.2)
13 Steam HX	- (0.30)	- (0.30)	- (0.3)
15 Binary HX	- (0.40)	- (0.40)	- (0.4)
<u>G-10 - Pilot Plant Design</u>	<u>- (1.00)</u>	<u>0.73(1.00)</u>	<u>1.00(1.00)</u>
01 Conceptual Design	- (0.10)	0.10(0.10)	0.10(0.10)
02 Detailed Design	- (0.80)	0.53(0.80)	0.80(0.80)
03 Site Selection	- (0.10)	0.10(0.10)	0.10(0.10)
<u>G-11 - Pilot Plant Construction</u>	<u>- (7.0)</u>	<u>- (7.0)</u>	<u>- (7.0)</u>
<u>G-12 - Pilot Plant Operation</u>	<u>- (3.0)</u>	<u>- (3.0)</u>	<u>- (3.0)</u>

TABLE 87. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-13 - Supporting Research</u>	<u>0.2(2.8)</u>	<u>0.4(2.8)</u>	<u>0.5(2.8)</u>
01 High Temp/Press Packing Material	- (0.2)	- (0.2)	- (0.2)
03 Production Drilling Imp.	- (0.4)	- (0.4)	- (0.4)
05 Subsidence-Seismic Research	0.2(0.6)	0.4(0.6)	0.4(0.6)
07 Instrumentation	- (0.4)	- (0.4)	0.1(0.4)
09 High Pressure Loop	- (1.2)	- (1.2)	- (1.2)
<u>G-14 - Environmental Studies</u>	<u>0.40(1.7)</u>	<u>1.10(1.7)</u>	<u>1.30(1.70)</u>
01 Subsidence-Seismic Model	0.50(0.2)	0.10(0.2)	0.10(0.20)
02 Site Survey	0.10(0.3)	0.30(0.3)	0.30(0.30)
04 Impact State- ment	0.10(0.30)	0.30(0.30)	0.30(0.30)
06 Waste Treat- ment Equip.	0.10(0.60)	0.30(0.60)	0.50(0.50)
08 Monitoring Studies	0.05(0.30)	0.10(0.30)	0.10(0.30)
<u>G-15 - Power Economic Analysis</u>	<u>0.05(0.70)</u>	<u>0.30(0.70)</u>	<u>0.35(0.70)</u>
01 Initial Resource Dev. Analysis	0.02(0.06)	0.06(0.06)	0.06(0.06)
03 Power Genera- tion Cycle Analysis	0.03(0.06)	0.06(0.06)	0.06(0.06)
05 Conceptual Design Anal.	- (0.06)	0.06(0.06)	0.06(0.06)
07 Design Optim- ization and Trade-off	- (0.17)	0.12(0.17)	0.17(0.17)
09 Reservoir Optimization	- (0.15)	- (0.15)	- (0.15)
11 Field Resource Economic Anal.	- (0.20)	- (0.20)	- (0.20)

TABLE 87. (continued)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>G-16 - Multiple Use of Resource</u>	<u>- (0.40)</u>	<u>0.10(0.40)</u>	<u>0.10(0.40)</u>
01 Alternative Applications	- (0.40)	0.10(0.40)	0.10(0.40)
<u>G-17 - Utilization Project</u>	<u>0.20(1.50)</u>	<u>0.40(1.50)</u>	<u>0.50(1.50)</u>
01 Seminar, etc.	0.10(0.20)	0.10(0.20)	0.10(0.20)
03 Professional Papers	0.05(0.15)	0.10(0.15)	0.10(0.15)
05 Handbooks, etc.	- (0.50)	- (0.50)	0.10(0.50)
07 Training Programs	- (0.30)	- (0.30)	- (0.30)
09 Film	- (0.10)	0.05(0.10)	0.05(0.10)
11 Public Info.	0.05(0.15)	0.10(0.15)	0.10(0.15)
13 Professional Societies	- (0.10)	0.05(0.10)	0.05(0.10)

FIGURE 20. Geopressure Geothermal Power - A Budget (Fiscal Year)

FIGURE 21. Geopressure Geothermal Power - B Budget (Fiscal Year)

FIGURE 22. Geopressure Geothermal Power - C Budget (Fiscal Year)

F. DRY STEAM

Location

Only a few dry steam occurrences are known. Three of these are currently commercial energy procedures: The Geysers, California; Larderello, Italy; and Matsukawa, Japan. There are two small fields in the Monte Amiata region of Italy, and a field in Java has been discovered recently.

Value of Resource

Larderello, Italy was the first geothermal field to be exploited (1904) and has a geothermal generating capacity of 358 MW.⁽¹⁾ The Geysers, California had an installed capacity of 400 MW by the end of 1974. The proven capacity of The Geysers' field is 750 MWe.⁽²⁾ The highest projected capacity for dry steam in the United States is 30,000 MWe,⁽³⁾ a nearly 100-fold increase over existing capacity.

State-of-the-Art

With the world capacity nearing 1,000 MWe, the generation of electricity from geothermal dry steam has been demonstrated. Dry steam contains as much as 55°C superheat and minor amounts of other gases (H₂S, CO₂, NH₃). After removal of particulates, the steam can be piped directly to a turbine. Although the dry steam reservoir pressure reaches 480 psig, the turbines at the Geysers are designed to operate at 80-100 psig intake pressure to compensate for expansion and cooling in the flowing steam.⁽⁴⁾

(1) Walter J. Hickel, Geothermal Energy, University of Alaska, p. 14, 1972.

(2) Geothermal Energy, Paul Kruger and Carel Otte, editors. Stanford University Press, Stanford, CA, p. 129, 1973.

(3) Personal communication - Bechtel Corp.

(4) Geothermal Energy, Paul Kruger and Carel Otte, op. cit., p. 130.

Geothermal steam is at much lower pressure than steam produced from conventional power plants, but current technology permits economic utilization of this steam to generate electricity.

Because production technology is adequate, a program for the expanded discovery and exploitation of geothermal dry steam offers a potential to help alleviate the national energy shortage in the near term. Other forms of geothermal energy, in contrast, depend on the development and demonstration of a suitable technology before large scale commercial production is feasible.

Well drilling now accounts for 40-60% of the total cost of geothermal power. Although "state-of-the-art" drilling is adequate for developing dry steam reservoirs, improvements in drilling technology could lead to reduced costs and provide added incentive for increased dry steam exploration and development.

Problems

Compared to other geothermal energy resources, dry steam has no major problems requiring large research expenditures. However, research in several areas could resolve current uncertainties and help stimulate more efficient utilization and development of this currently important energy source.

Geologic Modeling

A critical assessment of the current state of fundamental knowledge and theories of the geologic conditions for dry steam occurrences is required. Major uncertainties exist about the potential recoverable energy from this resource. The distribution of the recoverable energy throughout the U.S. is uncertain. The potential size and characteristics of individual reservoirs are unknown. The potential rate of production and producing life of a reservoir are unknown. These factors depend on numerous physical characteristics of the formation. Among these are temperature, pressure, permeability, porosity, rock and mineral composition, and the size and depth of the heat source.

A reservoir model should be developed which simulates the characteristics of dry steam reservoirs and aids in defining the depths, areal extent, and energy potential of dry steam reservoirs. A widely accepted geologic model which accurately describes the subsurface conditions would also help to clarify resource size and depletion characteristics which would aid in the regulation, tax treatment, and leasing of geothermal energy resources.

Stimulation

Steam contains only a fraction of the potential energy content in a reservoir; the remainder is in the rock. The development of a reservoir requires sinking several wells for each steam turbine and periodically replacing depleted wells with new ones. Stimulation techniques might be developed which increase the rate of production, reduce costs, and increase the amount of energy recoverable from a reservoir.

Environment

Environmental impacts are associated with geothermal dry steam energy production. Steam withdrawal and reinjection of the condensate carries a remote potential for affecting groundwater levels or quality at distant locations. Noise is a problem. The disruption of a natural habitat poses another problem. Air releases of water vapor, H_2S and other gases may degrade local air quality. The electrical transmission lines, well drilling activities and powerplant and road construction all impact the environment.

Development Strategy

With only one field in operation in this country, numerous other problems might be expected to arise with expanded development. However, most of these are expected to be resolved by private industry. The government sponsored research program for geothermal dry steam outlined below is directed toward projects which increase the energy resource base, encourage expanded commercial development, reduce environmental and social impacts, and encourage a balanced and efficient development of resources.

A program plan, Table 88, is outlined for each of the three reference budget levels (A, B and C). All projects in B and C Budgets are planned to be completed within the first 5-year period. The projects in A Budget which are not funded in the first five years are included in the second 5-year funding.

TABLE 88. Summary of Recommended Project Budgets for Dry Steam Resource Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>0.5 (4.5)</u>	<u>4.0 (4.0)</u>	<u>4.5 (4.5)</u>
S-00 Planning	0.02 (0)	0.1 (0.1)	0.15 (0.15)
S-03 Reservoir Modeling	0.19 (0.4)	0.3 (0.3)	0.4 (0.4)
S-05 Stimulation	0.05 (1.25)	1.25 (1.25)	1.25 (1.25)
S-06 Reinjection Technique	0 (0.1)	0.1 (0.1)	0.1 (0.1)
S-07 Power Generation Cycles	0.02 (0.1)	0.1 (0.1)	0.1 (0.1)
S-08 Thermochemistry	0 (0.1)	0.1 (0.1)	0.1 (0.1)
S-14 Environmental Studies	0.1 (1.0)	1.0 (1.0)	1.1 (1.1)
S-15 Power Economics Analysis	0.02 (0.3)	0.3 (0.3)	0.4 (0.4)
S-17 Utilization Plan	0.1 (0.8)	0.75 (0.75)	0.9 (0.9)

Projects

S-00 Planning Studies

These are Phase 0 planning and scoping studies.

TABLE 89. Summary of Recommended Budgets for Planning Studies Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
S-00 Planning Studies	0.02 (0.02)	0.1 (0.1)	0.15 (0.15)

S-03 Reservoir Modeling

A simulation model for dry steam reservoirs will be developed. The objective is to provide a simulation based on the reservoir properties which can be used to predict reservoir performance and the subsurface conditions. The modeling is funded at a uniform level over a four year period. The different funding levels refer to different degrees of model development and supporting research. Existing models will be evaluated.

TABLE 90. Summary of Recommended Budgets for Reservoir Modeling Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
S-03 Reservoir Modeling	0.19 (0.4)	0.3 (0.3)	0.4 (0.4)

S-05 Stimulation

There is no known current research activity on dry steam stimulation. Under Budget A, only a planning and feasibility study will be conducted (Task 01) to determine possible methods, techniques, and energy recovery potential from stimulation. If this task indicates substantial promise, the other tasks (02 Analyses of Rock Properties, and 03 Laboratory Stimulation Experiments) would be conducted, leading to a field test (Task 04) of the most promising stimulation technique(s). The well flow following the field test(s) would be monitored for a period of one year to determine the effect on flow rate (Task 05).

TABLE 91. Summary of Recommended Budgets for Stimulation Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>S-05 Stimulation</u>	<u>0.05 (1.25)</u>	<u>1.25 (1.25)</u>	<u>1.25 (1.25)</u>
01 Design Experiment	0.05 (0.05)	0.05 (0.05)	0.05 (0.05)
02 Analyze Rock Properties	0 (0.1)	0.1 (0.1)	0.1 (0.1)
03 Conduct Laboratory Tests	0 (0.2)	0.2 (0.2)	0.2 (0.2)
04 Field Tests	0 (0.8)	0.8 (0.8)	0.8 (0.8)
05 Test Monitoring	0 (0.1)	0.1 (0.1)	0.1 (0.1)

S-06 ReInjection Technology

Liquid waste is currently reinjected into the formation at The Geysers to avoid potential contamination of surface waters. Although this water may vaporize and prolong the life of the field, the actual behavior of reinjected water in a formation is unknown. Under B and C Budgets, a study (Task 01) of the kinetics of reinjection in a dry steam field will be undertaken. The study will evaluate the potential for this practice to decrease energy recovery (value) of the resource or to cause adverse effects which extend beyond the boundaries of a reservoir.

TABLE 92. Summary of Recommended Budgets for ReInjection Technology Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
S-06 ReInjection Technology	0 (0.1)	0.1 (0.1)	0.1 (0.1)

S-07 Power Generation Cycles

Current technology uses a steam cycle with a thermal conversion efficiency of about 15%. Analytical studies (Task 01) will be conducted to evaluate methods of increasing the conversion efficiency and extending the energy reserves. The studies will evaluate the effect of reservoir site, size, and conditions on the selection of the power generating cycle. These studies will be more detailed under the B and C Budgets.

TABLE 93. Summary of Recommended Budgets for Power Generation Cycles Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
S-07 Power Generation Cycles	0.02 (0.1)	0.1 (0.1)	0.1 (0.1)

S-08 Thermochemistry

Characterization and composition analyses of geothermal steam (Task 01) would be conducted under the B and C Budgets to provide fundamental information to be used in material selection, reservoir modeling, stimulation tests, reinjection technology, power cycle analyses, and environmental control studies. No funding is planned under the A Budget in the first five years.

TABLE 94. Summary of Recommended Budgets for Thermochemistry Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
S-08 Thermochemistry	0 (0.1)	0.1 (0.1)	0.1 (0.1)

S-14 Environmental Studies

The general seismic-subsidence model to be developed under the environmental subprogram would be adapted to the unique conditions of dry steam fields and evaluated (Task 01). A detailed site survey (Task 03) would be conducted and an environmental impact statement (Task 04) would be prepared in support of the stimulation field tests. Ground and surface water surveys (Task 06) would be conducted to provide detailed base line data and to monitor and evaluate the effects of geothermal power generation on the ground water resources in the surrounding region. Studies on the characterization and attenuation of noise emissions (Task 08) related to geothermal power plants would be conducted under the C Budget.

TABLE 95. Summary of Recommended Budgets for Environmental Studies Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>S-14 Environmental Studies</u>	<u>0.1 (1.0)</u>	<u>1.0 (1.0)</u>	<u>1.1 (1.1)</u>
01 Seismic-Subsidence Model	0.1 (0.2)	0.2 (0.2)	0.2 (0.2)
03 Site Survey	0 (0.3)	0.3 (0.3)	0.3 (0.3)
04 Impact Statement	0 (0.1)	0.1 (0.1)	0.1 (0.1)
05 Hydrology	0 (0.3)	0.3 (0.3)	0.4 (0.4)
06 Noise Release	0 (0)	0.1 (0.1)	0.1 (0.1)

S-15 Power Economic Analysis

A resource development analysis (Task 01) aimed at depicting the current status of dry steam reserves, the cost of development, and the potential for future expansion would be undertaken.

Other economic analyses and econometric modeling studies (Task 03) would be conducted throughout the 5-year period. These would include: (1) a parametric study projecting the costs of building and operating commercial dry steam plants covering the range of conditions expected for dry steam reservoirs, e.g., depth, size, flow rates, and other major factors which influence costs, (2) a sensitivity analysis describing probable impact on electricity generation costs and reserves for the run of conditions and new developments, and (3) an analysis of the potential market for dry steam energy. This latter analysis will include a comparative analysis with other sources of energy for each region of the nation where dry steam resources are projected to occur. The focus of these studies would be on techniques and incentives for achieving a large-scale expansion in dry steam capacity. Special (undefined) economic studies would be undertaken throughout this period to meet changing conditions and unforeseen needs. An econometric model for dry steam reservoirs would be developed under the C Budget.

TABLE 96. Summary of Recommended Budgets for Power Economic Analysis Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>S-15 Power Economics Analyses</u>	<u>0.02 (0.3)</u>	<u>0.3 (0.3)</u>	<u>0.4 (0.4)</u>
01 Resource Development Analysis	0.02 (0.3)	0.1 (0.1)	0.1 (0.1)
03 Econometric Modeling	0 (0.2)	0.2 (0.2)	0.3 (0.3)

S-17 Utilization Project

In order to promote widespread dissemination and utilization of research results, a special budget for this purpose is provided. Since the output from most of the projects will be research reports, the utilization project will use other channels to review, evaluate, summarize, apply, and distribute this information. These channels include sponsorship of seminars and other meetings (Task 01), professional papers and review articles (Task 03), handbooks and textbooks (Task 05), training programs (Task 07), public information films, pamphlets and brochures (Task 09), and support for professional and standards society activities (Task 11).

A close liaison between energy producers, energy consumers, and energy researchers will be promoted.

TABLE 97. Summary of Recommended Budgets for Utilization Project for Dry Steam Resources Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>S-17 Utilization Project</u>	<u>0.1 (0.8)</u>	<u>0.75 (0.75)</u>	<u>0.9 (0.9)</u>
01 Seminars	0.02 (0.1)	0.1 (0.1)	0.1 (0.1)
03 Professional Papers	0.03 (0.1)	0.1 (0.1)	0.15 (0.15)
05 Handbooks	0 (0.3)	0.3 (0.3)	0.3 (0.3)
07 Training Programs	-	-	-
09 Public Information	0.05 (0.2)	0.2 (0.2)	0.25 (0.25)
11 Professional Societies	0 (0.1)	0.05 (0.05)	0.1 (0.1)

Proof-of-Concept Experiments and Significant Milestones

1. Development of a computer program simulating dry steam reservoirs will be completed by September 1978, under the B and C Budgets. A more limited model will be prepared under the A Budget and will be completed in the following 5-year period.
2. A major stimulation experiment (POCE) in a dry steam reservoir will be conducted and evaluated by July 1979, under the B and C Budgets. This experiment would not be conducted until the next 5-year period under the A Budget.
3. An econometric optimization model would be developed for dry steam reservoirs under the C Budget by July 1978.

Project and task schedules for research on dry steam systems are shown in Figures 23-25. The research tasks are described in Appendix B. The complete budget for dry steam is shown in Table 98. This is a composite of the above projects.

TABLE 98. Summary of Recommended Budgets for
Dry Steam Resource Five- (and Ten-)
Year Budgets (in \$ millions)

	A Budget		B Budget		C Budget	
<u>Total</u>	<u>0.50</u>	<u>(4.05)</u>	<u>4.00</u>	<u>(4.00)</u>	<u>4.50</u>	<u>(4.50)</u>
<u>S-00 Planning Studies</u>	<u>0.02</u>	<u>(0.02)</u>	<u>0.10</u>	<u>(0.10)</u>	<u>0.15</u>	<u>(0.15)</u>
<u>S-03 Reservoir Modeling</u>	<u>0.19</u>	<u>(0.40)</u>	<u>0.30</u>	<u>(0.30)</u>	<u>0.40</u>	<u>(0.40)</u>
<u>S-05 Stimulation</u>	<u>0.05</u>	<u>(1.25)</u>	<u>1.25</u>	<u>(1.25)</u>	<u>1.25</u>	<u>(1.25)</u>
01 - Design Experiment	0.05	(0.05)	0.05	(0.05)	0.05	(0.05)
02 - Analyze Rock Properties	-	(0.10)	0.10	(0.10)	0.10	(0.10)
03 - Conduct Laboratory Tests	-	(0.20)	0.20	(0.20)	0.20	(0.20)
04 - Field Tests	-	(0.80)	0.80	(0.80)	0.80	(0.80)
05 - Test Monitoring	-	(0.10)	0.10	(0.10)	0.10	(0.10)
<u>S-06 Reinjection Modeling</u>	<u>(0)</u>	<u>(0.10)</u>	<u>0.10</u>	<u>(0.10)</u>	<u>0.10</u>	<u>(0.10)</u>
<u>S-07 Power Generation Cycles</u>	<u>0.02</u>	<u>(0.10)</u>	<u>0.10</u>	<u>(0.10)</u>	<u>0.10</u>	<u>(0.10)</u>
<u>S-08 Thermochemistry</u>	-	<u>(0.10)</u>	<u>0.10</u>	<u>(0.10)</u>	<u>0.10</u>	<u>(0.10)</u>
<u>S-14 Environmental Studies</u>	<u>0.10</u>	<u>(1.0)</u>	<u>1.00</u>	<u>(1.0)</u>	<u>1.10</u>	<u>(1.10)</u>
01 - Seismic-Subsidence Model	0.10	(0.20)	0.20	(0.20)	0.20	(0.20)
03 - Site Survey	0.00	(0.30)	0.30	(0.30)	0.30	(0.30)
04 - Impact Statement	0.00	(0.10)	0.10	(0.10)	0.10	(0.10)
05 - Hydrology	0.00	(0.30)	0.30	(0.30)	0.40	(0.40)
06 - Noise Release	0.00	(0.00)	0.10	(0.10)	0.10	(0.10)
<u>S-15 Power Economics Analysis</u>	<u>0.02</u>	<u>(0.30)</u>	<u>0.30</u>	<u>(0.30)</u>	<u>0.40</u>	<u>(0.40)</u>
01 - Resource Development Analysis	0.02	(0.30)	0.10	(0.10)	0.10	(0.10)
03 - Econometric Modeling	-	(0.20)	0.20	(0.20)	0.30	(0.30)
<u>S-17 Utilization Project</u>	<u>0.10</u>	<u>(0.80)</u>	<u>0.75</u>	<u>(0.75)</u>	<u>0.90</u>	<u>(0.90)</u>
01 - Seminars	0.02	(0.10)	0.10	(0.10)	0.10	(0.10)
03 - Professional Papers	0.03	(0.10)	0.10	(0.10)	0.15	(0.15)
05 - Handbooks	-	(0.30)	0.30	(0.30)	0.30	(0.30)
07 - Training Programs	-	-	-	-	-	-
09 - Public Information	0.05	(0.20)	0.20	(0.20)	0.25	(0.25)
11 - Professional Societies	-	(0.10)	0.05	(0.05)	0.10	(0.10)

FIGURE 23. Dry Steam Geothermal Power - A Budget (Fiscal Year)

FIGURE 24. Dry Steam Geothermal Power - B Budget (Fiscal Year)

FIGURE 25. Dry Steam Geothermal Power -
C Budget (Fiscal Year)

G. EXPLORATION

Objectives

A systematic exploration program for geothermal reservoirs has not yet been undertaken in this country at the level of effort needed to accurately determine the national or regional potential of this energy resource. Private industry is expected to perform a major part of this work, provided that economic incentives exist. The major objective of this project is to supplement and encourage industry's efforts to determine the location and scope of the geothermal resource and to develop it. Therefore, this research plan recommends funding for regional exploration throughout the five- and ten-year periods being considered in this report.

Much of the effort described in other sections of this research plan is directed toward the completion within five (or ten) years of several pilot plants for power generation. An immediate task of the exploration program must therefore be the location of adequate sites for these plants (POCE's).

To carry out exploration and assessment programs effectively, it is important to identify, test, and improve geothermal exploration and assessment methods. Funds for this work are included in Exploration Project X-13. This project is intended to support the development of methods for both exploration and assessment because many methods that are useful in finding geothermal reservoirs (exploration) are also applicable to detailed studies (assessment) of the reservoirs..

State-of-the-Art

Most of the geophysical techniques that are presently being used for geothermal exploration have been developed and used primarily for oil and mineral exploration. But it has become clear that exploration for geothermal reservoirs requires approaches different from those used for other resources. Reflection and refraction seismic surveys, for example, are vital in oil exploration, but in geothermal exploration they are useful primarily in studying the structural setting of a potential reservoir. At

present, the most effective approach involves a flexible combination of geological, geochemical, hydrological, thermal, passive seismic, and electrical methods.

Geothermal exploration to date has been concentrated in areas where hot springs exist. In these areas, geochemical and hydrological analyses can often provide an estimate of reservoir temperature and type, the character of fluids at depth, flow rates, and water recharge sources. But much of the total hydrothermal resource may have no surface expression other than thermal anomalies. Exploration for such reservoirs will require new downhole geochemical analysis techniques as well as surface and downhole geophysical methods. In addition, theoretical, laboratory, and field studies are needed to understand the thermodynamics, chemical processes, and isotopic relationships in hydrothermal systems. Predictions of areas of high potential will be facilitated by studies of the processes of plate (global) tectonics and regional tectonics.

Thermal measurements are a direct means for determining the location and extent of a geothermal anomaly. Temperature, temperature gradient, and heat flow surveys are perhaps the most effective tools, short of deep drilling, for exploration and assessment programs. Measurements are normally made in small diameter holes at depths up to 100 meters or more. Reliability increases with the depth at which the measurements are made. Groundwater movement strongly affects the thermal structure and is particularly likely to be a serious effect at shallow depths. However, even in massive bodies of crystalline rocks groundwater in faults and fractures can lead to erroneous thermal measurements. Reconnaissance surveys, of the scope needed for a national resource appraisal, would be greatly facilitated by the development of more efficient techniques for making thermal measurements and for detecting groundwater at depth. Theoretical studies and physical and mathematical model studies are needed to determine the relationships between the quantities measured and the geometry and thermal history of the system.

Many geothermal areas have been correlated with abundant microearthquake activity and a high level of seismic noise. These phenomena are

attributed to small ground and fluid movements in faulted or fractured hydrothermal zones. Passive seismic monitoring systems are relatively simple, mobile, and inexpensive to use, but methods are needed to determine noise characteristics, the causes of noise generation, the location of noise sources, and the extent, geometry, and nature of the geothermal reservoir.

Hydrothermal activity often produces large resistivity contrasts within hot rock. High temperature, the presence of conductive fluids, and alteration of the rock all tend to increase the conductivity in geothermal areas. For this reason, electrical and electromagnetic methods have received much attention. Many of the methods used are relatively simple in terms of instrumentation and logistics, but problems of data processing and interpretation are difficult due to the inhomogeneity of geothermal reservoirs. Furthermore, because there is no unique relationship between electrical conductivity and temperature, it is difficult to discriminate between currently active hydrothermal zones and zones which are no longer active.

Discussion of Plans

The cost of conducting a geothermal exploration survey of the entire country would greatly exceed the exploration funds recommended in this research plan. The recommended A, B and C Budgets for field exploration provide a means for conducting surveys of selected areas as an initial step in a national and regional geothermal resource assessment program. In addition, the results of this work should accelerate investment by private industry in geothermal exploration and development, and they will provide needed background and data for the development of exploration technology.

Vast land areas in the United States, particularly in the western third of the country, are considered to have potential for geothermal resources. Promising areas that can be identified are normally those which contain hot springs or young volcanic rocks. Available geothermal, geological, and hydrological data should be used in Task X-00, Scoping and Planning, to select specific areas for field exploration surveys.

The techniques and procedures to be used in geothermal exploration cannot be rigidly specified because each geothermal site possesses unique characteristics which are best studied in an exploration program specifically designed for that site. The primary elements in such a program would be geological, thermal, geochemical and hydrological surveys. Additional work involving electrical, electromagnetic, or passive seismic methods may be done in some cases. These studies will usually provide an estimate of the type, temperature, location, and extent of a geothermal reservoir. For the purpose of planning and funding an exploration program, it is necessary to delimit the work in some way. The guideline adopted here is that "exploration" should yield enough data to justify either the initiation of a significantly more detailed survey (assessment) or abandonment of the site.

Although the objectives of the exploration program are basically the same for the A, B and C Budgets, only a minimal amount of field exploration can be done at the level of funding indicated for the A (\$100 M) and B (\$300 M) Budgets. It is necessary to allocate sufficient funds to insure completion of the pilot plants. Consequently, a five- or ten-year exploration program that is consistent with the need to identify and develop new energy sources cannot be funded under the A or B Budgets. A related funding casualty in the 5-year A Budget is the drilling of deep wells to depths greater than 10,000 feet. This work is included as a project in Subprogram H (Assessment) but is funded on a 5-year basis in only the B and C Budgets. In the A Budget it is funded only in the 10-year plan. Deep drilling is important to the development of exploration technology in that it is the only definitive means for testing and evaluating geological and geophysical methods for locating and assessing the deeper parts of geothermal reservoirs.

A substantial increase in funds for Exploration Technology Development is provided in the B and C Budgets. The C Budget is probably adequately funded in all aspects of exploration. Field exploration in the C Budget is funded at a level which will permit limited exploration in areas which do not necessarily have surface expressions of hydrothermal activity but which may enlarge the total geothermal resource base.

The following table is a budget summary for the exploration subprogram.

TABLE 99. Summary of Recommended Project Budgets for Exploration Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>12.1 (13.5)</u>	<u>31.0 (37.3)</u>	<u>50.3 (65.4)</u>
X-00 Scoping and Planning	0.2 (0.3)	0.2 (0.3)	0.3 (0.4)
X-01 Field Exploration Program	6.0 (7.0)	10.8 (14.0)	25.0 (35.0)
X-13 Exploration Technology Development	5.9 (6.2)	20.0 (23.0)	25.0 (30.0)

Projects

X-00 Scoping and Planning

The purpose of this project will be to formulate cost effective and comprehensive plans for meeting exploration program objectives. A review of exploration technology will provide direction for the exploration technology development project. Field exploration plans will include the evaluation of existing data, the selection of study areas and exploration methods, and the coordination of field work. Exploration projects will be closely related to and coordinated with projects being conducted under the assessment subprogram. These reviews and planning studies should include input and reviews by recognized experts in the fields. The following table is a budget summary for the exploration scoping and planning project.

TABLE 100. Summary of Recommended Budgets for Scoping and Planning Project for Exploration Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>X-00 Scoping and Planning</u>	<u>0.2 (0.3)</u>	<u>0.2 (0.3)</u>	<u>0.3 (0.4)</u>
03 Planning Field Exploration	0.1 (0.15)	0.1 (0.15)	0.15 (0.2)
01 Exploration Technology Review	0.1 (0.15)	0.1 (0.15)	0.16 (0.2)

Detailed task sheets are included in Appendix B.

X-01 Field Exploration Program

This project will consist of field exploration to identify POCE sites and to initiate the collection of field data needed to stimulate industrial development and to evaluate the national and regional geothermal resource. Project funding supports both the short-term POCE site identification and the long-term regional exploration.

Sites needed for POCE's should be identified within the first year of the program so that they may be promptly assessed and verified. Exploration for these sites should be focused on areas of high geothermal potential which can be identified now.

The A and B Budgets for field exploration are minimal. Therefore, in order to focus on stimulating investment by private industry, exploration under the A and B Budgets should be directed to areas where the probability of finding exploitable geothermal reservoirs is considered to be high. Under the C Budget there should be an increased emphasis on expanding our knowledge of the distribution of geothermal reservoirs and on advancing the state-of-the-art in exploration techniques. The selected survey areas should therefore encompass a wide range of geological characteristics and should include areas which do not have hot springs.

The following table contains a budget summary for the field exploration project.

TABLE 101. Summary of Recommended Budgets for Field Exploration Project Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
X-01 Field Exploration Program	6.0 (7.0)	10.8 (14.0)	25.0 (35.0)
01 Identification of Sites for POCE Studies	-	3.0 (3.0)	5.0 (5.0)
02 National and Regional Exploration	6.0 (7.0)	7.8 (11.0)	20.0 (30.0)

A detailed task sheet is included in Appendix B.

X-13 Exploration Technology Development

This project will develop techniques for geothermal exploration and assessment. The budget recommended for this project is based on a review of available and proposed methods. Consideration was given to their apparent usefulness and to the probability of achieving significant advances in their development. In particular, reflection and refraction seismic methods and gravity and magnetic methods have been used and developed by oil and mining companies for many years and yet they appear to be of minor importance in geothermal applications. For these techniques, new funding at a high level during the time period of this program is unlikely to be fruitful. Moderate funding should be provided, however, to support innovative concepts that may pertain particularly to geothermal exploration.

Work done under this project will include conceptual studies, prototype system development, development of data collection and analysis techniques, and laboratory and field system testing. Exploration technology development for hot, dry rock sites may require a different emphasis from that for hot water or dry steam systems. For budgeting and management purposes, the exploration techniques are divided into nine categories, as shown in the following table. Under the A Budget, only techniques which have a high probability of contributing to the 5-year program are recommended for funding. This consideration limits the funding available for new geophysical methods. The B and C Budgets, which place more emphasis on a continuing appraisal of the national geothermal resource, include more funding for new geophysical methods. These new methods may require long development and testing periods; therefore, their expected contribution to short-term program objectives should be carefully evaluated. The following table is a budget summary for the exploration technology development project.

TABLE 102. Summary of Recommended Budgets for Technology Development Project for Exploration Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>X-13 Exploration Technology Development</u>	<u>5.9 (6.2)</u>	<u>20.0 (23.0)</u>	<u>25.0 (30.0)</u>
01 Electrical Methods	1.35 (1.35)	4.4 (5.2)	5.7 (6.8)
03 Thermal Methods	0.5 (0.5)	0.9 (0.9)	1.8 (2.2)
05 Active Seismic	0.3 (0.3)	0.9 (0.9)	1.0 (1.0)
07 Passive Seismic	0.65 (0.65)	2.4 (2.8)	2.9 (3.5)
09 Remote Sensing	0.6 (0.6)	1.7 (2.0)	1.7 (2.0)
11 Gravity and Magnetic	-	0.5 (0.5)	0.7 (0.7)
13 Downhole Geophysical Methods	1.35 (1.55)	5.9 (6.9)	6.6 (8.3)
15 Geochemical Methods	0.85 (0.95)	1.6 (1.8)	1.9 (2.3)
17 New Geophysical Methods	0.3 (0.3)	1.7 (2.0)	2.7 (3.2)

Detailed task sheets are included in Appendix B. The complete budget for exploration is shown in Table 103.

TABLE 103. Summary of Recommended Budgets
for Exploration Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>12.1(13.5)</u>	<u>31.0(37.3)</u>	<u>50.3(65.4)</u>
<u>X-00 Scoping and Planning</u>	<u>0.2(0.3)</u>	<u>0.2(0.3)</u>	<u>0.3(0.4)</u>
01 - Exploration Tech- nology Review	0.1(0.15)	0.1(0.15)	0.15(0.2)
03 - Planning Field Exploration	0.1(0.15)	0.1(0.15)	0.15(0.2)
<u>X-01 Field Exploration Program</u>	<u>6.0(7.0)</u>	<u>10.8(14.0)</u>	<u>25.0(35.0)</u>
01 - Identification of Sites for POCE Studies	0(0)	3.0(3.0)	5.0(5.0)
02 - National and Regional Explor- ation	6.0(7.0)	7.8(11.0)	20.0(30.0)
<u>X-13 Exploration Technol- ogy Development</u>	<u>5.9(6.2)</u>	<u>20.0(23.0)</u>	<u>25.0(30.0)</u>
01 - Electrical Methods	1.35(1.35)	4.4(5.2)	5.7(6.8)
03 - Thermal Methods	0.5(0.5)	0.9(0.9)	1.8(2.2)
05 - Active Seismic	0.3(0.3)	0.9(0.9)	1.0(1.0)
07 - Passive Seismic	0.65(0.65)	2.4(2.8)	2.9(3.5)
09 - Remote Sensing	0.6(0.6)	1.7(2.0)	1.7(2.0)
11 - Gravity and Magnetic	0(0)	0.5(0.5)	0.7(0.7)
13 - Downhole Geophysical Methods	1.35(1.55)	5.9(6.9)	6.6(8.3)
15 - Geochemical Methods	0.85(0.95)	1.6(1.8)	1.9(2.3)
17 - New Geophysical Methods	0.3(0.3)	1.7(2.0)	2.7(3.2)

H. ASSESSMENT

Assessment, as defined in this report, includes the determination of national, regional and local geothermal energy potentials. Therefore, a major assessment objective is to obtain an accurate estimate of geothermal energy potentials to facilitate future planning and development. Establishing a data center for acquisition, dissemination and analysis of geothermal data is a key element in the development of an accurate national resource assessment program. Data now available on geothermal resources are widely scattered and attempts to establish data centers have been limited under existing programs. Data available from federal, state and local governments, as well as universities, industry and private sources should be included in the system.

The acquisition of data is closely tied to the field exploration program described in the preceding section of this report. For the next five to ten years the results of that field work can be expected to be the primary basis for estimates of the national and regional geothermal resource. The field assessment studies recommended in this subprogram involve local surveys of explored sites that have been determined to merit further study. More specifically, these sites are only those which are needed for pilot plant (POCE) construction and which are considered to be potentially suitable for that purpose. Assessment surveys should be conducted so that final decisions can be made regarding pilot plant construction at these sites. Additional studies made after a POCE site has been selected will be funded directly under the appropriate resource POCE budget.

Geological/geophysical and hydrological models for accurately assessing geothermal data are needed. These models should be closely tied to exploration and technology developments in order to take full advantage of advancements in exploration state-of-the-art. Models are needed to characterize geothermal reservoirs of all types and to assess the potential of the reservoirs on the basis of observed reservoir responses to varying modes of pilot testing and development.

Deep drilling and modeling of deep portions of geothermal reservoirs have been prohibited by cost and a lack of high temperature drilling technology required for this type of exploration and development. Budget considerations indicate that under the A (\$100 M) Budget, deep drilling would not be accomplished within the 5-year period because of the need for development of drilling technology. But it does appear to be feasible to conduct limited deep drilling activities for assessment under a 10-year program. The B (\$300 M) and C (\$500 M) Budget programs would include deep reservoir assessment work.

In order to make the numbering system for the resource subprogram compatible with the system used for the resource subprograms, several projects are identified by the heading A-02. The following table is a summary of project budgets for assessment.

TABLE 104. Summary of Recommended Project Budgets
for Assessment Five- (and Ten-) Year
Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>8.7 (20.8)</u>	<u>33.0 (49.6)</u>	<u>74.7 (105.3)</u>
A-00 Scoping and Planning	0.3 (0.4)	0.4 (0.5)	0.5 (0.6)
A-02 Geothermal Resource Appraisal	2.3 (3.3)	3.9 (5.9)	4.5 (7.5)
Field Assessment Project	4.2 (4.2)	12.2 (12.2)	28.2 (28.2)
Assessment Modeling	1.9 (2.9)	4.0 (6.0)	6.0 (9.0)
Deep Reservoir Assessment	0 (10.0)	12.5 (25.0)	35.5 (60.0)

Projects

A-00 Scoping and Planning

This project will be directed toward obtaining the cost/performance data needed for formulating the most cost effective and comprehensive program plans for meeting the assessment program objectives. Plans will be formulated for developing a comprehensive data center and a continuing

assessment program for national and regional assessment studies. An assessment technology review will be conducted to determine the most effective field assessment techniques for identified geothermal sites. A review of all types of models applicable to the assessment of geothermal resources should be conducted to determine specific needs. Deep reservoir assessment plans should be formulated for the B and C Budgets. These review and planning studies should include input and reviews by recognized experts in the field. The following table is a budget summary for the assessment scoping and planning project.

TABLE 105. Summary of Recommended Budgets for Scoping and Planning Project for Assessment Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>A-00 Scoping and Planning</u>	<u>0.3 (0.4)</u>	<u>0.4 (0.5)</u>	<u>0.5 (0.6)</u>
01 Resource Assessment Program Planning	0.1 (0.1)	0.1 (0.15)	0.15 (0.20)
03 Assessment Technology Review	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
05 Model Review	0.1 (0.1)	0.1 (0.15)	0.1 (0.15)
07 Deep Drilling Planning	0 (0.1)	0.1 (0.1)	0.15 (0.15)

Detailed task sheets are included in Appendix B.

A-02 Geothermal Resource Appraisal

This is one of the key projects under assessment in that it includes the continuing national and regional assessment program and the development of the data center which will receive and format all available data on geothermal resources. Establishing a comprehensive data center is critical to the assessment program because accurate assessment will depend on the consideration given to all available data. It will be necessary to interface this center with other national data centers and make access available to government, industrial and private users. The national and regional assessment studies will be designed to make use of data from historical

records and from ongoing exploration and assessment programs as they become available. These programs will provide data needed for future planning and development of geothermal resources. The following table is a budget summary for the geothermal resource appraisal project.

TABLE 106. Summary of Recommended Budgets for Geothermal Resource Appraisal Projects for Assessment Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>A-02 Geothermal Resource Appraisal</u>	<u>2.3 (3.3)</u>	<u>3.9 (5.9)</u>	<u>4.5 (7.5)</u>
01 Geothermal Data Center	1.5 (2.0)	2.4 (3.4)	2.5 (4.0)
03 National and Regional Resource Assessment	0.8 (1.3)	1.5 (2.5)	2.0 (3.5)

Detailed task sheets are included in Appendix B.

A-02 Field Assessment Project

Geothermal reservoirs identified by exploration field studies will be assessed under this project to determine their suitability as POCE sites. Field studies would include application of appropriate field assessment techniques, including the drilling and logging of test wells to verify reservoir type, temperature, and extent. Geological and hydrological characteristics would be studied in order to evaluate the ability of the reservoir to support production wells at required fluid withdrawal rates. These studies would be limited to sites required for POCE projects. The following table is a budget summary for the field assessment project.

TABLE 107. Summary of Recommended Budgets for Field Assessment Project Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>A-02 Field Assessment Project</u>	<u>4.2 (4.2)</u>	<u>12.2 (12.2)</u>	<u>28.2 (28.2)</u>
05 Field Work at Identified Sites	4.2 (4.2)	12.2 (12.2)	28.2 (28.2)

The detailed task sheet is included in Appendix B.

A-02 Assessment Modeling

In order to assess geothermal sites accurately on the basis of the limited data available from exploration and assessment field studies, improved techniques are needed for analyzing the data. Development of models which can be used for this purpose appears to be one of the most promising approaches available.

Geological/geophysical and hydrological models should be developed to characterize the various types of geothermal reservoirs. Data that become available from the study of developed reservoirs should provide input needed for model calibration and verification. Field assessment studies and operation of pilot plants will provide data needed for development of models to determine reservoir capacity accurately. Funds are also included under the resource budgets for the testing and modification of the models to accommodate specific reservoir variables. The following table is a budget summary for the assessment modeling project.

TABLE 108. Summary of Recommended Budgets for Assessment Modeling Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>A-02 Assessment Modeling</u>	<u>1.9 (3.0)</u>	<u>4.0 (6.0)</u>	<u>6.0 (9.0)</u>
07 Geological/Geophysical Model Studies	0.95 (1.5)	2.2 (3.5)	3.5 (5.5)
09 Hydrological Model Studies	0.95 (1.5)	1.8 (2.5)	2.5 (3.5)

Detailed task sheets are included in Appendix B.

A-02 Deep Reservoir Assessment

Optimum development of a geothermal reservoir will require an understanding of the factors which control the temperature distribution and the heat transfer processes at depth. These studies should include determining the configuration and temperature of the heat source as well as the lithology, hydrology, and stratigraphy of the reservoir. This project will include the drilling of several deep exploration wells to study these factors. In order to take advantage of previous studies and to maximize the probability of penetrating a geothermal reservoir, the wells should be located at sites that have been selected for pilot plant operation or at sites that have already been developed. Well logging and deep, downhole geophysical and geochemical measurements will provide data for the detailed assessment of these sites, including needed lower boundary conditions for modeling the upper portions of the reservoirs. Analytical studies will develop models and guidelines for the exploration, assessment, and utilization of similar geothermal reservoirs. A further utilization of these wells will be the testing, evaluation, and calibration of geological and geophysical techniques for exploration and assessment of deep geothermal resources.

Many technological and funding problems have prevented the drilling of deep exploration holes into known geothermal reservoirs. Funds for the development of drilling equipment and techniques are included in the Drilling subprogram (Section I). Development of downhole geophysical logging equipment capable of operating reliably under high temperatures and in corrosive fluids will also be required before significant data can be derived from a deep drilling program. Funds have been provided under Exploration for the development of downhole instrumentation. Deep drilling probably should not begin before 1976 so that the results of these development programs may be utilized. Projected costs for deep drilling within the next five to ten years will depend on numerous factors and can only be roughly estimated. For the purpose of deriving the budget for this project, the combined drilling and downhole measurement costs for a 20,000-foot (6.1 km) hole in hot rock are assumed to be \$4 M. A 15,000-foot hole would

be approximately \$1 M less; a 25,000-foot hole approximately \$1.5 M more. The following table is a budget summary for the deep reservoir assessment project.

TABLE 109. Summary of Recommended Budgets for
Deep Reservoir Assessment Five- (and
Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>A-02 Deep Reservoir Assessment</u>	<u>0 (10.0)</u>	<u>12.5 (25.0)</u>	<u>35.5 (60.0)</u>
11 Deep Reservoir Drilling	0 (8.5)	10.6 (21.0)	32.2 (52.0)
13 Deep Reservoir Modeling	0 (1.5)	1.8 (4.0)	3.3 (8.0)

Detailed task sheets are included in Appendix B. The complete budget for assessment is presented in Table 110.

TABLE 110. Summary of Recommended Budgets
for Assessment Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>8.7(20.8)</u>	<u>33.0(49.6)</u>	<u>74.7(105.3)</u>
<u>A-00 Scoping and Planning</u>	<u>0.3(0.4)</u>	<u>0.4(0.5)</u>	<u>0.5(0.6)</u>
01 Resource Assessment Program Planning	0.1(0.1)	0.1(0.15)	0.15(0.20)
03 Assessment Tech- nology Review	0.1(0.1)	0.1(0.1)	0.1(0.1)
05 Model Review	0.1(0.1)	0.1(0.15)	0.1(0.15)
07 Deep Drilling Planning	0(0.1)	0.1(0.1)	0.15(0.15)
<u>A-02 Geothermal Resource Appraisal</u>	<u>2.3(3.3)</u>	<u>3.9(5.9)</u>	<u>4.5(7.5)</u>
01 Geothermal Data Center	1.5(2.0)	2.4(3.4)	2.5(4.0)
03 National and Regional Resource Assessment	0.8(1.3)	1.5(2.5)	2.0(3.5)
<u>A-02 Field Assessment Project</u>	<u>4.2(4.2)</u>	<u>12.2(12.2)</u>	<u>28.2(28.2)</u>
05 Field Work at Identified Sites	4.2(4.2)	12.2(12.2)	28.2(28.2)
<u>A-02 Assessment Modeling</u>	<u>1.9(3.0)</u>	<u>4.0(6.0)</u>	<u>6.0(9.0)</u>
07 Geological/Geo- physical Model Studies	0.95(1.5)	2.2(3.5)	3.5(5.5)
09 Hydrological Model Studies	0.95(1.5)	1.8(2.5)	2.5(3.5)
<u>A-02 Deep Reservoir Assessment</u>	<u>0(10.0)</u>	<u>12.5(25)</u>	<u>35.5(60)</u>
11 Deep Reservoir Drilling	0(8.5)	10.7(21.0)	32.2(52.0)
13 Deep Reservoir Modeling	0(1.5)	1.8(4.0)	3.3(8.0)

I. DRILLING

Objectives

The development of drilling technology is a critical element in the geothermal energy development program. Deep reservoirs which are not now accessible may be economically developed with advanced drilling technology. A major objective of this subprogram is the development of drilling techniques which will make it economically feasible to tap these reservoirs. Development of hot dry rock systems, in particular, will depend upon the ability to penetrate the reservoir to a temperature which will allow the heat exchange system to operate economically. Research in deep wells is needed to determine the characteristics of the deeper parts of geothermal reservoirs. These studies will provide data needed in the development of techniques and models for both exploration and assessment, and will facilitate the prediction of reservoir lifetime and power production capacity.

State-of-the-Art

In conventional drilling a rotating drill bit is used within the hole. The bit is powered from the surface through connecting drill pipe. Drilling at great depths and high temperatures puts severe demands on the torque capacity of the drive system and the strength of the drill string. These great depths could require techniques which eliminate the rotation of the shaft. Promising ways of doing this include locating the motor for rotation near the hole bottom or using graduated drilling or melting techniques. Numerous technical and economic factors will determine the feasibility of deep drilling. They include rotating drill table capacity, drill pipe strength, bit strength and design, and downhole temperature, pressure, and rock competence. Special drilling fluids are required for the higher temperatures and pressures encountered in deep drilling. Hole collapse, water invasion, and drilling fluid loss are three related and currently encountered problems which may be anticipated. At some depth and diameter, a hole cannot be cased with existing methods because the weight of the string overstresses the casing and associated handling equipment.

Nonconventional or novel techniques can be classified by the basic mechanism utilized for rock removal.⁽¹⁾ The various mechanisms include: (1) fusion and vaporization, (2) thermal spalling, (3) chemical reactions, and (4) mechanically induced stresses. The specific novel methods listed below have been classified according to these rock-removal mechanisms. Conventional rotary drilling falls in the last category.

Classification of Novel Drills

Fusion and Vaporization Drills

Electric Arc	Nuclear
Electric Heater (subterrene)	Plasma
Electron Beam	Laser

Thermal-Spalling Drills

Electric Disintegration	Induction
Forced Flame	Jet Piercing
High Frequency	Microwave

Chemical Drills

Fluorine

Mechanical Drills

Continuous Penetrator	Pellet
Erosion	Spark
Explosive	Turbine (single stage)
Implosive	Ultrasonic

Fusion and vaporization drills must operate at the rock melting temperature. The melting temperatures of most rocks range from 1000 to 2000°C, and the specific energy required to fuse rock ranges from 1.15 to 1.4 watt-hours/cubic centimeter. Strong igneous rocks such as granite and basalt have lower fusion energy requirements than weaker sedimentary rocks such as sandstone and limestone. This suggests that fusion drills will find initial application for drilling these strong igneous rocks.

(1) William C. Maurer, "New Drilling Methods Move Close to Field," The Oil and Gas Journal, pp. 74-79, February 26, 1968.

Electric heater drills (the subterrene)⁽¹⁾ and nuclear drills⁽²⁾ are similar except for heat source. Both melt the rock and remove it as a fragmented solid. The subterrene, a particular hole melting device, shows potential for applications in the future. The device, which is under active development at the Los Alamos Scientific Laboratory, bores holes in rocks by progressive melting.

Electric arc drills operate at 5,000 to 17,000°C and can fuse holes in any rock. Work has been done by several organizations.⁽³⁾ As an example, Drilling Research, Inc.⁽⁴⁾ used an electric arc to spall and fuse craters in flint, limestone, and sandstone.

Plasma generators or plasma arc drills produce temperatures up to 17,000°C and are capable of fusing holes in any rock. Plasmas are produced by passing electrical current through a gas, such as helium or argon, which is passing between electrodes at velocities of 200 to 7,500 meters per second. Plasma drills are high-velocity, high-heat-transfer devices.

Electron-beam drills⁽⁵⁾ produce power concentrations up to 1.5×10^9 watts per square centimeter, sufficient to fuse holes in any rock. Electron beams are produced by accelerating electrons from a cathode toward an anode using potentials of 5 to 150 kilovolts. The electrons emitted from the cathode are focused against the rock by means of a bias grid along with electrostatic and electromagnetic lenses.

Laser drills⁽⁶⁾ can produce power concentrations on the order of 10^{12} watts per square centimeter, which are sufficient to fuse holes in any rock.

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- (1) "The First Practical Application of the Subterrene", The Atom, 10, No. 4, May 1973.
 - (2) W.M. Adams, "Nuclear Reactor Apparatus for Earth Penetration", U.S. Patent #3155194, 1965.
 - (3) William C. Maurer, "New Drilling Methods Move Close to Field", The Oil and Gas Journal, pp. 74-79, February 26, 1968.
 - (4) Drilling Research Inc., Annual Reports, Houston, 1969-63.
 - (5) R. Bakish, Introduction to Electron Beam Technology, Wiley & Sons, New York, 1962.
 - (6) R.A. Gladstone and A. Kettaneh. News release regarding use of lasers to thermally degrade rock. Office of Public Relations, Massachusetts Institute of Technology, Cambridge, November 24, 1966.

A laser beam is produced by exciting or "pumping" a group of atoms in a crystal or gas to their higher energy state. As they drop back to their lower energy state, the atoms emit photons of a fixed frequency, producing a coherent light beam.

When the surfaces of some rocks are rapidly heated to 400 to 600°C, thin flakes or "spalls" of rock break off the surface. This process, called thermal spalling, produces long, thin flakes. These spalls are produced by thermal stresses resulting from differential thermal expansion of the constituent crystals and grains.

Jet-piercing drills⁽¹⁾ are widely used for drillign taconite and other silicate ores. They burn oxygen and fuel oil to produce a flame having a temperature of 2400°C and a velocity of 1800 meters per second. Water is used to cool the combustion chamber and the burning nozzles. This water also solidifies the molten rock and is converted to steam, which assists in removing the distintegrated rock from the hole bottom. Jet-piercing drilling rates range from 0 in limestone to 12 meters per hour in some taconites and quartzites.

Forced-flame⁽²⁾ or rock-exhaust drills are similar to jet-piercing drills except that they use nitric acid as the oxidizing agent instead of oxygen. Nitric acid produces a faster reaction, resulting in higher power output and faster drilling rates. A field-tested, forced-flame drill penetrated iron quartzite in 18 meters per hour, compared to 5 meters per hour for a jet-piercing drill.⁽³⁾

Numerous tests have shown that high-frequency electric current can be used to break and crush conductive rocks such as iron ore.⁽⁴⁾ This technique could be used to drill rock. These devices heat rock by dielectric heating and by resistance heating. Dielectric heating occurs due to the

(1) I.H. Rubow, "Jet Piercing in Taconite", Mines Magazine, Colorado School of Mines, March, 1956.

(2) V.S. Kravchenko, A.P. Obvastov and V.V. Ustinov, "Dustless Breaking of Rocks Electrically", Min. Congr. Journal, pp. 53-55, May 1961.

(3) William C. Maurer, "Thermal Spalling, Chemical Drills", The Oil and Gas Journal, pp. 69-75, March 4, 1968.

(4) Ibid., Ref. 2 above.

rapid switching back and forth of the dipoles, while resistance heating is produced by electric current passing through the rock between the electrodes.

Ross⁽¹⁾ has patented a thermal drill (called the Terra Jetter) which cyclically heats and cools rock. As conceived, superheated steam (250 to 500°C) would heat the rock for three minutes and then liquid nitrogen (-134°C) would be sprayed on the heated rock to thermally shock and pulverize it. Low-pressure steam would be circulated through the drill to remove the pulverized rock from the hole bottom and to reheat the rock.

Sarapuu⁽²⁾ has used the electric-disintegration drill to drill limestone, taconite, and concrete. This drill heats and spalls rock by passing low-frequency electric current (60 cps) into the rock through a sharp bit. The bit is rotated at 90 rpm and air is sprayed on the rock to thermally shock and break it.

Laboratory tests have shown that microwaves (1000 to 3000 Mhz) can effectively heat and break rock. Microwaves produce dielectric heating, which is proportional to the frequency of the field. This technique could be used for drilling wells.

Chemical drills use highly reactive chemicals such as fluorine to drill rock at high rates. These drills have successfully drilled sandstone, limestone, and granite in laboratory tests. They have limited potential because of the difficulty in handling large quantities of highly reactive chemicals and because of the high cost of these chemicals.

Energy sources for mechanical drills are not necessarily mechanical since explosive, erosion, and spark drills fall in this classification. These drills induce mechanical stresses in the rock by impact, erosion, and abrasion. When these stresses exceed the tensile or shear strength of the rock, the rock fails in a brittle or plastic manner.

(1) "Methods of an Apparatus for Splitting Nonmetallic Brittle Materials," English Patent No. 1019737, 1966.

(2) E. Sarapuu, "Electrical Disintegration Drilling," Rock Mechanics, Pergamon Press, pp. 173-184, 1963.

The turbine drill⁽¹⁾ has been extensively tested in oil wells. A single-stage turbine is used to rotate a diamond-faced cutter wheel at speeds of 5,000 to 10,000 rpm. The drill pipe is rotated at 30 to 75 rpm, producing a hemispherical hole bottom. Part of the thrust applied to this drill is transmitted to the spring-loaded cutter wheel, and part is transmitted to the rock through diamond reamers at the bottom of the drill.

Carter Oil Company⁽²⁾ developed a pellet drill. This drill breaks rock by impacting it with steel pellets which are recirculated through the bit. Following impact, the pellets are lifted by the rising fluid to an opening near the top of the drill where they reenter the bit. "Gauge-feeler" feet at the bottom of the drill maintain proper standoff distance between the bit and the rock. This bit is rotated to expose the rock under these feet.

Howe⁽³⁾ has proposed the continuous penetrator. A high thrust would continuously push the penetrator through the rock, crushing the rock ahead of it and pushing it aside. Since no bit is used, it would eliminate pulling drill pipe to change worn bits. It would also eliminate the need for circulating fluid to remove cuttings from the well. The thrust would be applied by drill collars, by impact loads, or by wall anchors that grip the borehole walls and hydraulically load the penetrator.

Ostrovskii⁽⁴⁾ has proposed using implosions to drill. These drills would produce implosions by pumping hermetically sealed capsules to the bottom of the hole and breaking them against the rock. The high hydrostatic pressure existing in oil wells would produce intense implosions.

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- (1) G.E. Cannon, "Development of a High-Speed, Low-Torque Drilling Device," presented at Fall AIME meeting, Dallas, October 6-9, 1957.
 - (2) J.E. Eckel, F.H. Deily and L.W. Ledgerwood, "Development and Testing of Jet Pump Pellet Impact Drill Bits," Trans. AIME 207, pp. 1-9, 1956.
 - (3) R.J. Howe, Esso Production Research Co., Houston. Personal communications, 1963.
 - (4) N.P. Ostrovskii, "Deep-Hole Drilling With Explosives," Gostopekhia 'dat. Moscow. Translation by Consultants Bureau Enterprises, Inc., New York, 1960.

Ultrasonic drills⁽¹⁾ are used commercially for drilling hard materials such as diamonds and ceramics. With extensive development they could potentially be used to drill rock. Magnetostrictive or electrostrictive sound sources, vibrating at frequencies of 20 to 30 kHz, produce cavitation in fluid next to the rock face; the cavities impact, crush, and abrade the rock.

Spark, or electrohydraulic drills⁽²⁾ use high-energy sparks to break and remove rock from the hole. Sparks, which last from 1 to 50 μ sec, are produced by high-voltage capacitors charged to 30 to 70 kv. The capacitors are fired from 1 to 10 times per second, producing pressure pulses in excess of 70,000 newtons per square centimeter.

The Russians have extensively tested an explosive drill. This drill pumps explosive capsules to the hole bottom, where they detonate on impact with the rock. A capsule contains two nonexplosive liquids separated by an impermeable membrane. As the capsule passes through a constriction near the bottom of the drill pipe, this membrane is broken and the liquids form an explosive mixture. When a capsule strikes the hole bottom, a percussion pin strikes a detonator that initiates the explosion.

Erosion drills using high-pressure water jets can drill hard rocks at high rates, provided a threshold pressure drop is exceeded across the nozzles. This threshold pressure, which is a function of rock strength and hydrostatic pressure in the well bore, ranges from less than 1400 newtons per square centimeter to over 14,000 newtons per square centimeter.

Discussion of Plans

Limitations imposed by the A Budget will largely restrict the drilling development program to the improvement of conventional methods with no

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- (1) A.P. Sviridov, "Semiautomatic Ultrasonic Device," Izvestiya Vysshikh Uchebnykh Zavedenii: Priborostroenie U.S.S.R., No. 2, p. 159, 1958.
 - (2) L.A. Yutkin, "Electrohydraulic Effect," Mashgiz (State Scientific Technical Press for Machine Construction Literature), Moscow, 1955. Translation No. AD-267-722, Armed Services Technical Information Agency, Arlington Hall Station, Arlington, VA.

significant investigation of novel methods. The cost of the development of new drilling methods is such that the A Budget will finance little more than direct support for the pilot plant, exploration, and assessment subprograms. The B and C Budgets will provide increasing levels of funding for promising new drilling techniques. The following table is a budget summary for the drilling subprogram.

TABLE 111. Summary of Recommended Project Budgets for Drilling Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>7.0 (20.3)</u>	<u>31.1 (70.4)</u>	<u>53.0 (100.5)</u>
D-00 Scoping and Planning	0.2 (0.3)	0.3 (0.4)	0.4 (0.5)
D-09 Drilling Development	6.8 (20.0)	30.8 (70.0)	52.6 (100.0)

Projects

D-00 Scoping and Planning

This project will consist of examining and evaluating drilling needs with regard to depths involved, number of holes to be drilled, capabilities and limitations of existing equipment and technology, postulated research and development needs, and probable costs. Existing techniques and equipment will be compared with future needs, as they are presently understood; gaps in technology will be identified, areas in which extension of current techniques may be feasible will be defined, and methods presently in the developmental stage will be examined.

Planning will consist of developing a program to support the development of techniques that appear to be promising for meeting drilling needs. Recommendations for research and development directions will be made. The following table is a budget summary for the drilling scoping and planning project.

TABLE 112. Summary of Recommended Budgets for Scoping and Planning for Drilling Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>D-00 Scoping and Planning</u>	<u>0.2 (0.3)</u>	<u>0.3 (0.4)</u>	<u>0.4 (0.5)</u>
01 Review Drilling Technology	0.1 (0.15)	0.15 (0.2)	0.2 (0.25)
03 Plan Drilling Developments	0.1 (0.15)	0.15 (0.2)	0.2 (0.25)

Detailed task sheets are included in Appendix B.

D-09 Drilling Development

This project will develop drilling equipment and techniques capable of deep drilling in geothermal reservoirs. It will encompass research on materials and rock mechanisms as well as extensive design, development and testing of drilling tools, fluids and new techniques. Novel drilling techniques will receive increased financing under the B and C Budgets. The following table is a budget summary for the drilling development project.

TABLE 113. Summary of Recommended Budgets for Drilling Development Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>D-09 Drilling Development</u>	<u>6.8 (20.0)</u>	<u>30.8 (70.0)</u>	<u>52.6 (100.0)</u>
01 Drilling Tool Development	1.1 (3.0)	5.2 (10.0)	8.3 (15.0)
03 Drilling Fluid Development	0.7 (2.0)	3.6 (7.0)	5.3 (10.0)
05 Drilling Techniques	5.0 (15.0)	22.0 (53.0)	39.0 (75.0)

Detailed task sheets are included in Appendix B. For details of the costs and objectives of these tasks, the reader is referred to the Appendix.

TABLE 114. Summary of Recommended Budgets
for Drilling Five- (and Ten-)
Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>7.0(20.3)</u>	<u>31.1(70.4)</u>	<u>53.0(100.5)</u>
<u>D-00 Scoping and Planning</u>	<u>0.2(0.3)</u>	<u>0.3(0.4)</u>	<u>0.4(0.5)</u>
01-Review Drilling Technology	0.1(0.15)	0.15(0.2)	0.2(0.25)
03-Plan Drilling Developments	0.1(0.15)	0.15(0.2)	0.2(0.25)
<u>D-09 Drilling Development</u>	<u>6.8(20)</u>	<u>30.8(70)</u>	<u>52.6(100)</u>
01-Drilling Tool Development	1.1(3)	5.2(10)	8.3(15)
03-Drilling Fluid Development	0.7(2)	3.6(7)	5.3(10)
05-Drilling Technique	5.0(15)	22(53)	39(75)

J. ENVIRONMENTAL-SOCIAL

Although the environmental impacts and the social acceptance of geothermal power are expected to present few obstacles to its development (compared to other energy resources), there are certain studies which are essential. In earlier years some of the projects recommended here would have been termed unnecessary. In this age all socio-environmental problems must be researched in advance of the introduction of a new technology, both to satisfy the requirements of the National Environmental Protection Act and a growing social awareness of the public.

Problems

The potential environmental impacts of geothermal power generation have been discussed widely in the literature.^(1,2) Even though the geothermal plants concentrate all environmental effects (mining, transportation, generation, waste disposal) of the generation cycle at a single site, there may still be major impacts which must be understood. While all of these effects will be site dependent to some extent, there are others which can be studied on a generic basis. The results of these generic studies can then be applied to the specific sites as needed.

The related problems of land subsidence and seismic disturbance probably have the greatest potential for serious environmental impact. The withdrawal of large amounts of fluid without reinjection from some geologic formations will almost certainly cause subsidence of the overlying surface. This subsidence may be accompanied by seismic activity. Likewise, the reinjection of fluids into certain formations may induce seismic activity.

The stimulation of geothermal reservoirs by conventional or nuclear explosives has the potential for causing seismic activity. Since most

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- (1) R.G. Bowen, "Environmental Impact of Geothermal Development," Geothermal Energy, pp. 197-215, Stanford University Press, 1973.
 - (2) G.W. Sandquist and G.A. Whan, "Environmental Aspects of Nuclear Stimulation", Geothermal Energy, pp. 293-313, Stanford University Press, 1973.

geothermal anomalies are located in areas of high seismicity, the problem is more acute than in most underground explosions.

The gaseous, liquid, and solid wastes from geothermal production must be understood. Such gases as hydrogen sulfide and ammonia may be released. Methods must be developed to hold emissions to a safe level for release or else they must be reinjected into the earth. Liquid wastes may present problems if released to surface waters if they contain noxious elements such as boron or arsenic. Even reinjecting such wastes could be dangerous if the hydrology of the reinjection formation is unfavorable or poorly understood. In the case of hot waters and brines there may be large quantities of objectionable solids produced from some conversion cycles. These must be disposed of in an environmentally sound manner.

Land use is a concern inasmuch as 7000-9000 acres per 1000 MWe are needed.⁽¹⁾ These secondary fluids, particularly fluorinated hydrocarbons, have the potential for new environmental effects.

In the past the societal impacts of new technologies have been largely ignored in advance of their introduction. In post facto analysis of these effects it is often determined that major irreversible commitments should not have been made. Research should be undertaken to assess the social-cultural impacts created by the development of geothermal energy. Procedures would be developed and tested in two broad areas. The first involves approaches for disseminating information about the first-order environmental impacts of geothermal energy to the public and for ascertaining societal priorities and attitudes which will be vital inputs for policy resolution and decision making. The second area of research would be the general assessment of tradeoffs which society is willing to make among increased energy demands, environmental considerations, and changes in life styles.

To date, few appropriate methodologies for examining societal reactions to technological change have been developed. Social psychologists have

(1) R.G. Bowen, "Environmental Impact of Geothermal Development," Geothermal Energy, p. 200, Stanford University Press, 1973.

recently conducted exploratory research of this nature. These new methods should be developed to the point where the societal reaction to geothermal technology can be assessed in the field.

Development Strategy

The plans for generic environmental studies are premised on the need for basic environmental-social research which is independent of resource type. The rapid transfer of this work to specific resources and sites is planned. The three budgets do not vary as much as do some of the other sub-programs. The reason for this is the fact that the basis of these effects must be understood before the first pilot plants can be built and run. As the number and diversity of these plants increase, so will the necessary level of research. Most of this research should be done prior to plant construction; hence, the major expenditures fall in the first five years.

The program plan is outlined in Table 115 for each of the three budget levels.

TABLE 115. Summary of Recommended Budgets for Environmental-Social Research Five- (and Ten-) Year Budgets
(in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>3.8 (5.2)</u>	<u>8.0 (11.4)</u>	<u>10.3 (12.0)</u>
E-00 Scoping and Planning	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
E-14 Environmental Studies	3.5 (4.9)	7.7 (11.1)	10.0 (11.7)

The details of the projects and tasks are shown in the following section.

Projects

E-00 Planning Studies

Plans should be made for the environmental-social studies to insure that these results will be available in time to contribute to the

environmental impact statements which will have to be prepared for the pilot plants. Likewise, there should be careful integration of these studies with the site-oriented planning studies to insure that field data are gathered in the correct format. The level of this planning work does not change with the three budget levels. The budget is shown in Table 116.

TABLE 116. Summary of Recommended Budgets for Planning Studies
Project for Environmental-Social Subprogram Five-
(and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>E-00 Planning Studies</u>	<u>0.3 (0.3)</u>	<u>0.3 (0.3)</u>	<u>0.3 (0.3)</u>
Environmental	0.28 (0.28)	0.28 (0.28)	0.28 (0.28)
Social	0.02 (0.02)	0.02 (0.02)	0.02 (0.02)

E-14 Environmental Studies

The generic environmental and social problems inherent in geothermal generation will be studied under this project. The major task will be the development of a generalized model of seismic-subsidence effects. The individual resources will provide funds for gathering data and testing this model at the various pilot plant sites. Work on this model will be expanded somewhat under the B and C Budgets to include the effects of stimulation and fracturing experiments. The disposition of all wastes will be studied in one task. As the brine and hot rock pilot plants are increased in the B and C Budgets, so will the scope of this particular task. Noise suppression research will increase only slightly between the three budgets. Safety studies will increase as the number and variety of plants increase. The potential effects to be expected from various alternative cycles will have to be studied in depth before their adoption. For example, before a hydrocarbon primary working fluid could be considered for a dry rock application, its reaction products, their characteristics and toxicities, should be well understood and factored into system designs. The social studies should expand somewhat as the number of pilot plants increase, for it will be important to recognize the regional and local variations in public reaction to geothermal energy.

Table 117 shows the details of the recommended budgets for this project.

TABLE 117. Summary of Recommended Budgets for
Environmental Studies Project Five-
(and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>E-14 Environmental Studies</u>	<u>3.5 (4.9)</u>	<u>7.7 (11.1)</u>	<u>10.0 (11.7)</u>
01 Seismic Subsidence Model	2.0 (2.5)	2.9 (3.5)	3.5 (3.5)
03 Waste Studies	0.5 (0.5)	2.2 (4.0)	3.0 (4.0)
05 Noise Suppression	0.25 (0.5)	0.8 (0.8)	0.8 (0.8)
07 Compatible Land Use	0.2 (0.5)	0.4 (0.5)	0.7 (0.7)
09 Land Rehabilitation	0.15 (0.2)	0.4 (0.7)	0.4 (0.7)
11 Impacts Alternative Cycle	0.1 (0.3)	0.3 (0.8)	0.6 (0.8)
13 Social Studies	0.3 (0.4)	0.7 (0.8)	1.0 (1.2)

The entire environmental-social subprogram by project and task is summarized in Table 118.

TABLE 118. Summary of Recommended Detailed Budgets
for Environmental-Social Subprogram Five-
(and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>E. Environmental-Social Studies</u>	<u>3.8 (5.2)</u>	<u>8.0 (11.4)</u>	<u>10.3 (12.0)</u>
<u>E-00 Planning Studies</u>	<u>0.3 (0.3)</u>	<u>0.3 (0.3)</u>	<u>0.3 (0.3)</u>
Environmental Social	0.28 (0.28)	0.28 (0.28)	0.28 (0.28)
Social	0.02 (0.02)	0.02 (0.02)	0.02 (0.02)
<u>E-14 Environmental Studies</u>	<u>3.5 (4.9)</u>	<u>7.7 (11.1)</u>	<u>10.0 (11.7)</u>
01 Seismic Subsidence Model	2.0 (2.5)	2.9 (3.5)	3.5 (3.5)
03 Waste Studies	0.5 (0.5)	2.2 (4.0)	3.0 (4.0)
05 Noise Suppression	0.25 (0.5)	0.8 (0.8)	0.8 (0.8)
07 Compatible Land Use	0.2 (0.5)	0.4 (0.5)	0.7 (0.7)
09 Land Rehabilitation	0.15 (0.2)	0.4 (0.7)	0.4 (0.7)
11 Impacts Alternative Cycle	0.1 (0.3)	0.3 (0.8)	0.6 (0.8)
13 Social Studies	0.3 (0.4)	0.7 (0.8)	1.0 (1.2)

K. INSTITUTIONAL STUDIES

It is recognized that ownership rights, tax treatment, leasing privileges, regulations and management may have a far more profound effect on the rate of geothermal development than the technology. It is, of course, important that geothermal power be developed in an economically sound and environmentally sound fashion, considering the public interest as well as the producer's. However, if geothermal power is to be developed rapidly, every effort must be made to encourage and facilitate its use. Studies combining the legal, economic, social and technical aspects of geothermal energy can make major contributions to the policy and legislative solutions required to resolve some of these problems and help set the stage for constructive regulation.

Institutional Problems

Numerous legal, regulatory, tax and leasing questions are currently delaying private development of geothermal power. A few examples are:

1. Leasing of public land is progressing slowly.
2. Because of the above, geothermal development of private land is often delayed. The surrounding property may be public land and the private leaseholders do not wish to encourage outside bids on this land. This has been amply discussed by Mossman⁽¹⁾ and others. Mossman points out that the explorer must overlease the prospect in order to have enough of a demonstrated reserve to induce the generating company to invest in a long-payout plant.
3. Some states are withholding state land from geothermal development. The reasons for this are not clear. It may be that they are awaiting the development of federal regulations and leasing policies.

(1) M.H. Mossman, "Requirements for Private Industry in Developing Geothermal Energy", Colorado Geothermal Conference, Denver, December 6, 1973.

4. Ownership of geothermal water or heat is not clear. It is not clear whether oil or gas laws, mineral laws or water laws apply.
5. The allowable tax treatment is not clear. Can depreciation allowances and write-offs for drilling expenses be taken? The only ruling, so far, is on The Geysers where depletion and write-off were allowed on the basis that steam is a gas.⁽¹⁾ This precedent obviously would not apply to hot water or hot rock systems. As has been discussed by Finn,⁽²⁾ the effect of tax uncertainty can have a serious effect on the rate of geothermal development. Since the tax treatments which are now under question can have a profound effect on the developer's eventual rate of return, this uncertainty is a major element of risk. As Finn states:
"Sophisticated investors always seek means of eliminating risk or uncertainty to the extent possible." Given two similar investments, they will always choose the one with the lower risk.
6. Regulations on land use, drilling permits, allowable production rates, disposal of water produced, and disposal of gases like H₂S are not developed.
7. Government assistance in R&D development of new types of plants is not clear. Although ERDA is taking the lead in geothermal development, some twelve major government agencies and the Congress are involved in various aspects of geothermal development.
8. There is no easy way for a utility to obtain financing for geothermal plants in other than dry steam areas. Utilities usually require the demonstration of an adequate energy supply for a given size plant for a lifetime of 25-35 years. This requires the producer to make a large investment and wait, perhaps five years, for his first dollar of revenue.

(1) Arthur E. Reich v. Commissioner of Internal Revenue, 52 Tax Court 700 (1969). Affirmed 454 F. 2d 1157 (9th Circuit 1972).

(2) D.F.X. Finn, "Federal Tax Policy and Geothermal Energy Development", Geothermal Energy, p. 39, October 1973.

There are numerous other problems relating to the sale of power, transmission lines, operating regulations, etc.

It is proposed that the following studies be funded to provide assistance to the Congress, federal, state and local and agencies to help resolve the above list of problems.

TABLE 119. Summary of Recommended Project Budgets for Institutional Studies Five- (and Ten-) Year Budgets (in \$ millions)

	<u>A Budget</u>	<u>B Budget</u>	<u>C Budget</u>
<u>Total</u>	<u>1.3 (1.3)</u>	<u>1.3 (1.3)</u>	<u>1.3 (1.3)</u>
I-00 Scoping and Planning	-	-	-
I-01 Legal Questions	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
I-02 Tax (Subsidy) Questions	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
I-03 Regulatory Structure and Procedures	0.4 (0.4)	0.4 (0.4)	0.4 (0.4)
I-04 Follow-Up Studies	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
I-05 Geothermal Organization	0.2 (0.2)	0.2 (0.2)	0.2 (0.2)